

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
10 May 2002 (10.05.2002)

PCT

(10) International Publication Number
WO 02/37069 A1(51) International Patent Classification⁷: G01J 4/00

(21) International Application Number: PCT/US01/45343

(22) International Filing Date: 30 October 2001 (30.10.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/244,689	30 October 2000 (30.10.2000)	US
60/244,738	30 October 2000 (30.10.2000)	US
60/311,621	8 August 2001 (08.08.2001)	US
60/311,443	8 August 2001 (08.08.2001)	US

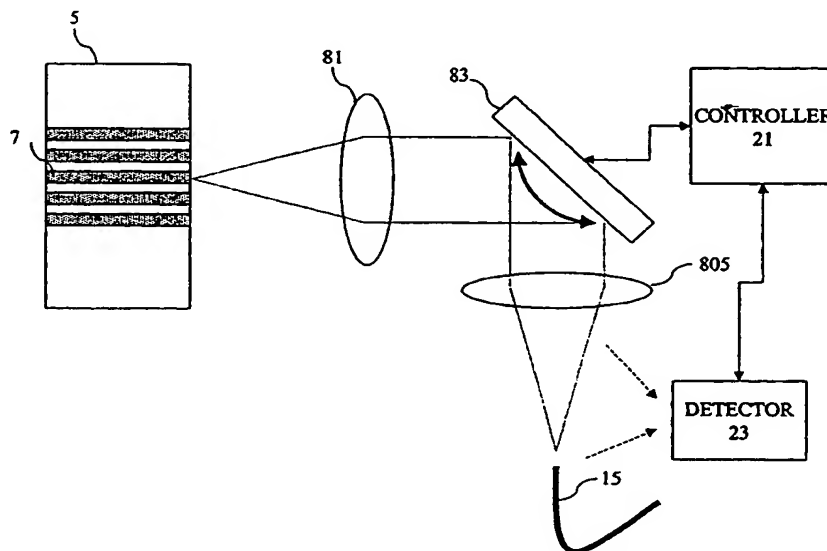
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(US).(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU,
CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM,
HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK,
LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX,
MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL,
TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.(84) Designated States (*regional*): ARIPO patent (GH, GM,
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,
IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,
CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD,
TG).

Published:

— with international search report

[Continued on next page]

(54) Title: LASER AND FIBER COUPLING CONTROL



(57) Abstract: One or more single mode waveguide devices are fiber coupled such that signals to an optical element affect the coupling of the waveguide device to an optical fiber (15). A number of systems and methods are disclosed to adjust the coupling of the waveguide device to the optical fiber. These include dithering the tunable optical element (25) at different frequencies along differing axes and using a lock-in technique to derive an error signal for each degree of motion, using a beamsplitter (121) to form a secondary image of the focused beam on a position-sensitive detector (23), the use of a chisled fiber to generate reflections from the angled facets, using an additional laser for a secondary image, or obtaining a secondary image from an angled fiber or a parasitic reflection.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LASER AND FIBER COUPLING CONTROL

BACKGROUND

The present invention relates generally to lasers and in particular to controlling fiber coupling between an array of lasers and an optical output.

Fiber coupling is often an essential but costly step in packaging various waveguide devices for telecommunication applications. On account of the very small optical modes in single mode waveguide devices, very tight submicron tolerances are often required in the packaging.

Generally, the devices are actively aligned. For example to fiber couple a telecommunication laser, the device is activated, and the optical power coupled to the fiber is monitored as the positions of the various optical elements in the package are varied. When the coupling is maximized, the optical elements are permanently fixed in position. The process is time consuming, costly, and often not very reproducible due to contraction in epoxies or thermal expansion of the components.

Furthermore, all the components in the package should be made absolutely immobile for the above procedure to maintain effectiveness over time. Any change in the position of the elements decreases the optical coupling. This makes hybrid integration of components with varying expansion coefficients very difficult. For example, to package a laser with a lithium niobate modulator, the laser uses hard solder for thermal heatsinking, while the modulator uses a soft epoxy that does not stress the crystal. The relative position of these devices will vary in the package due to the mismatch in the materials. Similarly, solders and epoxies tend to cause stress in the fiber, which affects yield and reliability and can cause birefringence in the fiber that influences the polarization of light in the core.

BRIEF SUMMARY OF THE INVENTION

The present invention provides adjustable optical coupling systems and methods. In one embodiment, a laser from an array of lasers is selected in which each laser emits light at different wavelengths. An optical path from the laser to an optical output is established such that light

1 from the laser is transmitted into an optical output. The optical path established is adjusted to
maximize output power of the emitted light into the optical output. In one aspect of the
invention, a look-up table is established where the table has entries in which individual lasers in
5 the laser array are each assigned an output power value and an entry in the look-up table that
corresponds to the selected laser is identified. In another aspect of the invention, a look-up table
is established where the table has entries in which individual lasers in the laser array are each
assigned a predetermined output power value and associated with a predetermined location
10 identified for the optical element. An entry in the look-up table that corresponds to the selected
laser is identified.

In one embodiment, the system comprises an array of lasers, at least one optical element
and an optical output such that light from a laser from the array of lasers is directed into the
15 optical output by the at least one optical element. A controller is also coupled to the at least one
optical element and configured to adjust the optical element to maximize output power of the
light directed into the optical output. In one aspect of the invention, the system also comprises
a plurality of photodetectors proximate the optical output. The controller is coupled to the
20 plurality of photodetectors and is configured to adjust the optical element based on the
information provided by the photodetectors. The information provided by the photodetector
comprises optical output power of light received at one or more of the photodetector and/or a
location of light incident upon one or more of the photodetectors. In another aspect of the
invention, the controller generates an error signal to adjust the optical element.
25

In a further embodiment, the system comprises an array of lasers having lasers configured
to emit light, an optical output configured to receive light and a detector near the optical output.
The system also includes at least one optical element configured to receive light from a laser
from the array of lasers and to direct a portion of the light to the optical output and a portion of
30 light to the detector. A controller is coupled to the at least one optical element and configured
to adjust the at least one optical element to maximize output power of the light directed into the
optical output. In one aspect of the invention, the optical element comprises a beam splitter
and/or a mirror.

35 In a further embodiment of the invention, the system comprises an array of lasers

1 comprising a first laser and a second laser where the first laser is configured to emit light and the
second laser is configured to emit light. An optical output is also provided and configured to
receive light from the first laser. The detector near the optical output is configured to receive
5 light from the second laser. Also, at least one optical element is provided and configured to
receive light from the first and second lasers and a controller is coupled to the at least one optical
element and configured to adjust the at least one optical element to maximize output power of
the light into the optical output. In other aspects of the invention, the second laser is a
10 predetermined distance from the first laser.

In another embodiment of the present invention, the system comprises emitting means
for emitting light having differing wavelengths, output means, and optical means for directing
light having a particular wavelength from the emitting means into the output means. Coupled
15 to the optical means is control means that also adjusts the optical means to maximize power of
the light directed into the output means. In another aspect of the invention, the system further
comprises reflective means for reflecting light from the emitting means and directed to the output
means. In another aspect of the invention, the system provides sensing means for sensing light
and is proximate the output means. The control means is coupled to the sensing means and
20 adjusts the optical means based on light sensed by the sensing means.

Many of the attendant features of this invention will be more readily appreciated as the
same becomes better understood by reference to the following detailed description and
considered in connection with the accompanying drawings.
25

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates one embodiment of an optical transmission apparatus having an
individually addressable multi-wavelength laser array directly coupled to a 1:N micro-mechanical
30 switch;

FIG. 2 illustrates one embodiment of an optical transmission apparatus with a control
system;

FIG. 3 illustrates another embodiment of an optical transmission apparatus in which light
35 is provided to a fiber via a movable mirror being dynamically controlled;

1 FIG. 4 illustrates one embodiment of an optical transmission apparatus with a magnetically movable mirror;

 FIG. 5 illustrates one embodiment of an electrostatic movable mirror;

5 FIG. 6 illustrates one embodiment of an optical transmission apparatus with a control system;

 FIG. 7 illustrates a flow diagram of one embodiment of adjusting an optical element to maximize fiber coupled power;

10 FIG. 8 illustrates a flow diagram of one embodiment of adjusting an optical element to maximize fiber coupled power;

 FIG. 9 illustrates a flow diagram of one embodiment of adjusting an optical path to maximize fiber coupled power;

15 FIG. 10 illustrates a dithering control system and capable of controlling various embodiments of an optical transmission apparatus;

 FIG. 11 illustrates one embodiment of a control system using a chiseled fiber and capable of controlling various embodiments of an optical transmission apparatus;

20 FIG. 12 illustrates one embodiment of a control system using an angle cleaved fiber and capable of controlling various embodiments of an optical transmission apparatus;

 FIG. 13 illustrates one embodiment of a control system using a beam splitter and capable of controlling various embodiments of an optical transmission apparatus;

25 FIG. 14 illustrates one embodiment of a control system using parasitic reflectivity and capable of controlling various embodiments of an optical transmission apparatus; and

 FIG. 15 illustrates one embodiment of a control system using a guide laser and capable of controlling various embodiments of an optical transmission apparatus.

30 DETAILED DESCRIPTION

 FIG. 1 shows an array of single frequency lasers, such as distributed feedback (DFB) lasers, on a semiconductor substrate. The array of lasers comprises a number of independently addressable lasers 7. Each laser has a separate contact pad 3 from which current is injected into
35 the laser. Each laser is designed to operate at a different lasing wavelength, by, for example,

1 varying the grating pitch in the laser or adjusting the effective index of the optical mode through
varying the stripe width or the thickness of the layers that compose the laser. When current is
injected into the laser using for example contact pads 3, the laser emits radiation with a specific
5 wavelength and from a particular position on the chip, as represented by the arrows 9. In one
embodiment, one laser is operated at a time, depending on the desired wavelength. The radiation
or light from the lasers is transmitted to a micro-mechanical optical switch or switching element
11. The switching element has a number of states. In each particular state of a set of states, one
10 of the input optical beams, i.e., light from one of the lasers, is transferred to the output 13 and
transferred to the output fiber 15. The entire assembly is packaged together on one submount 19.

The fabrication of multi-wavelength laser arrays is relatively well known in the art. To
assign different wavelengths to each laser, a number of techniques can be used, such as directly-
15 written gratings with electron beam lithography, stepping a window mask during multiple
holographic exposures, UV exposure through an appropriately fabricated phase mask, or
changing the effective index of the mode of the lasers. Generally, for stable single mode
characteristics, either a controlled phase shift is also included in the laser or gain/loss coupling
is used in the grating. The wavelength of such lasers can be accurately controlled through
20 dimensional variables, and varied across the array.

The lasers, switching element, and other components are more fully described in the
commonly assigned patent application entitled Tunable Controlled Laser Array, filed on October
30, 2001 the disclosure of which is incorporated by reference.

25 One exemplary embodiment of the switching element 11 is shown in the system of FIG.
2. In the embodiment illustrated in FIG. 2, current is provided to a laser element of the laser
array, e.g., laser element 7, and thereby the laser element emits light. The light from the laser
element is then directed by an optical element 25 to an optical output, e.g., an optical fiber 15.
30 The optical element, in one embodiment, is a moveable mirror. The optical element, in various
other embodiments, is a combination of mirrors, lens, beam splitters or other types of stationary
and/or movable optical components, such that light from any particular laser or one or more
lasers is directed to the optical fiber. Additionally, the optical element, in various embodiments,
35 directs light or a portion of the light to a detector 23. In other embodiments, the optical output

1 provides light or a portion of the light to the detector.

Over time or due to certain conditions, e.g., thermal effects or packaging disturbances, the laser to fiber coupling arrangement may require alignment or adjustment.

5 A controller 21 with the detector 23 identifies and corrects for misalignments. The detector 23 senses, in various embodiments, a position of the light beam or a measure of the power of light beam at a predefined position. In one embodiment, the detector 23 determines the power of the light focused into the optical fiber. The controller receives the positional and/or
10 power information from the detector, and determines if the fiber coupling arrangement should be adjusted. As such, the controller, in one embodiment, generates a signal used to adjust the fiber coupling arrangement. In one embodiment, the controller is a digital signal processor configured to receive and interpret power and/or positional information from the detector and to
15 generate and issue adjustment commands to the optical element.

In FIG. 3, one embodiment of an optical element of FIG. 2 is shown. The light from laser element 7 is collimated by a lens 81 and strikes a moveable mirror 83. The mirror reflects the light to a lens 805 which focuses the light into an optical output, e.g., an optical fiber 15.

20 The fabrication of micro-mechanical tip/tilt mirrors, such as the mirror 83, are well known in the art. Both surface micromachining techniques and bulk silicon etching have been used to make such mirrors. In general, the precision required for a mirror used with the present invention is considerably less than that of large cross connect switches, as the modes of the laser array are closely spaced.. Thus, the pointing accuracy for the optical apparatus is considerably
25 reduced.

In one embodiment, controller 21 consults a look-up table to determine an initial position of the mirror upon selection of a laser, and thereafter induces slight movement of the mirror to determine a preferred position. For instance, the controller maintains a lookup table of the mirror
30 positions in conjunction with the selection of each of the lasers in the laser array. A detector sensing light from the mirror or the optical fiber provides a signal to the controller, the signal providing positional and/or power information regarding the light. Based on the values in the lookup table and the measurements performed by the detector, the controller determines which
35 direction the mirror should be moved in order to provide optimal output power. Thus, as

1 appropriate, the controller produces a control signal to move the mirror, for example, in a first
or second direction. The second direction is a direction that is substantially opposite from the
first direction. The mirror, in one embodiment, is continually commanded to wander and the
5 output power monitored to compensate for movement of components of the package, thermal
effects and other causes of potential misalignment and thereby provide maximum output power.

In a further embodiment, the controller determines if the positional and/or power
information from the detector differs from a predetermined optimal positioning of the
10 arrangement and/or a predefined maximum or optimal optical power of the light. Based on
positional and/or power differences determined by the controller, the controller moves the mirror.
For example, if the detector indicates that the light is at position X1, and the controller, by
referring to the look-table, determines that the light should be at position Y1, the controller
15 causes the mirror to move. As such, when the mirror is moved, the fiber coupling arrangement
is adjusted. In other words, the mirror reflects the light from the laser and to the optical fiber,
but to a different point or position. In this manner, the detector and controller measure the light
to the optical fiber and adjust the mirror accordingly. Therefore, misalignments are corrected and
optical power of the light at the optical fiber is maximized. Various embodiments of the detector
20 determining the positional and/or power information regarding the light into the optical fiber and
the controller adjusting the mirror or other optical elements is described in greater detail later.

FIG. 4 shows a schematic of one embodiment of an optical system with a magnetically
25 moveable mirror. In the diagram a laser array chip 5 comprises a number of different laser
elements 7, each of which has a different set of characteristics. Depending on the system
requirements, the light from one particular laser element is used and directed by the optical train
to an output fiber 15.

30 In the particular embodiment illustrated in FIG. 4, the light from the laser element is
collimated by a fixed focusing lens 81 and impinges on a mirror 83. Once reflected from the
mirror, the light is focused by a second lens 805 and is coupled to the output fiber. In one
embodiment, the collimating lens and the second lens are replaced by a single lens. The single
35 lens is positioned approximately in the position of the collimating lens of FIG. 4, with the mirror

1 located at the back focal plane of the lens.

2 The mirror's rotation angle is adjusted both to select the beam of a particular laser, and
3 also to maintain the optimal coupling to the optical output. Two magnets 85 attached to the rear
4 of the mirror are positioned within solenoids 87. Wires 89 are attached to the solenoids. A
5 control current applied through the wires 89 controls the magnetic field which pulls one magnet
6 into the solenoid and pushes the other magnet out. Together with a fixed pivot point 803 and a
7 spring 801, the angle of the mirror is tuned, i.e., tilted, using the control current.

8 FIG. 5 illustrates another embodiment of a moveable mirror. The mirror has three
9 sections, a first section 151, a second section 153 and a third section 155. The first section 151
10 is stationary and is coupled to the second section 153 via torsion hinges 151a and 151b. The
11 second section rotates about torsion hinge 151a, i.e., about a first axis 157. The third section is
12 coupled to the second section via torsion hinges 153a and 153b. As such, third section also
13 rotates about the first axis when the second section rotates. Additionally, the third section rotates
14 about the torsion hinges 153a and 153b, i.e., about a second axis 159. The third section is also
15 coated with or is made of a reflective material so that light from a laser is reflected off the third
16 section. By moving the section and third sections about the respective first and second axes, the
17 mirror is able to direct light from a laser to a multitude of positions.

18 In one embodiment, portions of the sections are each plated or otherwise made
19 conductive. From an external source (not shown), voltage is applied between the plated portions
20 and a substrate below the mirror. As such, the portions act as capacitor plates and thus an electric
21 field is generated. Through the interaction of the charge on the mirror and the electric field
22 generated, a force is generated, such that the sections move or rotate. The amount of force
23 generated is based on the distance or gap between the portions. In other embodiments, thermal
24 actuators are used to position the mirror.

25 FIG. 6 illustrates another embodiment of a control system in accordance with the present
26 invention. An array of lasers 5 is formed on a substrate. In the embodiment described twelve
27 lasers are provided, and each of the lasers produces light at a different wavelength, with the
28 wavelengths centered around 1550 nanometers which is useful for fiber optic
29 telecommunications. The lasers are distributed feedback (DFB) lasers, although in different
30

1 embodiments the lasers are distributed Bragg reflector (DBR) lasers or vertical cavity surface
emitting lasers (VCSELs). The VCSELs may be arranged linearly, as are the DFBs and DBRs
in preferred embodiments, but the VCSELs are generally arranged in a two dimensional array.

5 Light from the lasers is passed through a collimating lens 61 and then to a moveable
MEMS structure 63. As illustrated the MEMS structure is a two axis tilt mirror, such as described
in U.S. Provisional Patent Application No. 60/309,669, entitled MEMS Mirror, filed August 2,
2001, the disclosure of which is incorporated by reference. The mirror is moved via a MEMS
10 control 65 by applying voltages to contact pads, resulting in rotation of the mirror in what for
convenience will be described as the x and y axis. As illustrated, the light is then reflected from
a second mirror 67 to a fiber 15. In alternative embodiments a prism is used to cause the light
to reach the fiber. Using either the second mirror or the prism allows the laser and other
15 components to be packaged in a butterfly package of the type generally used for laser light
sources in telecommunications systems.

20 In various embodiments an optical isolator 69 is placed between the second mirror and
the fiber. The optical isolator prevents, for example, stray reflections, from the end of the fiber
or from discontinuities in the telecommunication's line, from returning to the laser. Also in
various embodiments a modulator is placed after the optical isolator, or in its place, to modulate
the light with an information signal.

25 In one embodiment a quad detector 601 is placed between the second mirror and the fiber.
The light from the second mirror is reflected onto the quad detector which generates photocurrent
in the four sections A, B, C and D. The ratio of these currents are stored and used for maintaining
alignment. For instance, the ratio of the currents generated in sections A and B of the quad
detector are measured and stored. Also, the ratio of the currents generated in sections C and D
of the quad detector are measured and stored. An electronic control loop is then configured to
30 maintain these ratios during the operation of the device. When the device is first packaged, a
calibration procedure is performed in which the currents to the different sections of the quad
detector are measured when the beam is optimally aligned. These current values are stored and
used in the operation of the device. By operating the MEMS mirror in a feedback loop to keep
35 the ratios of these currents the same, the optical beam will point in the same direction and thus

1 maximum fiber coupling will be maintained. In one embodiment, generated photocurrents are provided to the MEMS control 65. Based on the generated photocurrents, the MEMS control produces an x axis control signal and a y axis control signal. Using these control signals or a
5 signal or signals representative thereof the MEMS control positions the mirror.

In other embodiments, the quad detector is placed behind the second mirror or a third mirror is provided to direct light to the quad detector. Various operation and placement of the quad detectors and photodetectors relative to the other components in the package are also
10 discussed, for example, in U.S. Provisional Patent Application No. 60/244,789, the disclosure of which is incorporated by reference.

- In one embodiment, external to the package is an optional wavelength locker 603. As illustrated, the wavelength locker is an inline wavelength locker, although in various
15 embodiments the wavelength locker is connected to the fiber by a tap. The wavelength locker illustrated in FIG. 6 determines the strength of light at two wavelengths about a selected wavelength. This is done, for example, by reflecting a portion of the transmitted light to two photodetectors. The transmitted light to a first of the photodetectors is of a wavelength slightly
20 below the selected wavelength. The transmitted light to a second of the photodetectors is of a wavelength slightly above the selected wavelength. Various wavelength lockers are known to those of skill in the art.

Generally, a wavelength error signal is formed using the ratio of the output of the two photodetectors. For example, the output of the first photodetector may be considered as forming the
25 numerator, and the output of the second photodetector may be considered as forming the denominator. In such a circumstance, it may be seen that if the wavelength is too high the ratio will decrease, and if the wavelength is too low the ratio will decrease. Formation of the ratio, or a signal indicative of the ratio, may be accomplished using comparators, differential amplifiers, calculation by a microprocessor (following analog-to-digital conversion), or the like. The
30 wavelength error signal is used for slight adjustments to the wavelength of the laser, using for example temperature tuning, particularly for DFB lasers, or charge injection for DBR lasers.

In the embodiment described the output of the photodetectors in the wavelength locker
35 is also used as an indication of output power from the laser. The output of the photodetectors, for

1 example, is summed by a summer. The output of the summer is an output power indicator, and
is provided to a control element. The control element produces a x axis control signal and a y axis
control signal using the control signal, or a signal or signals representative thereof. The x axis
5 control signal and the y axis control signal is used to position the mirror.

In one embodiment the control element maintains a lookup table of mirror positions for
selection of each of the twelve lasers. The lookup table is populated, in one embodiment, at the
time of manufacture of the package. On receipt of a command to select a particular laser, the
10 control element reads the appropriate values from the lookup table and generates the
corresponding x axis control signal and y axis control signal.

Due to movement of components of the package, thermal effects, and other causes of
potential misalignment, the control signals generated using the lookup table may not
15 appropriately position the mirror. Accordingly, in one embodiment the mirror position is
commanded to wander slightly, with the output power indicator monitored to determine the
mirror position providing maximum output power.

In another embodiment, the light from a tap on the fiber is provided to a photodetector.
The photodetector produces a signal that is proportional to the output power of the light from the
20 tap and is provided to the controller. The controller adjusts the mirror based on previous signals
provided by the wavelength locker or an initial calibration.

A flow diagram of a process for determining position of the mirror is provided in FIG.
7. In Block 71 the process determines a selected laser based on a laser select command. In Block
25 73 the process determines the appropriate control signals using a lookup table of expected mirror
positions for selected lasers. In Block 75 the process samples the power output indicator and
stores the result as an initial result.

In Block 76 the process determines if the laser/fiber coupling position should be
30 optimized. It may be desirable to interrupt the optimization process occasionally (e.g., when
switching between lasers).

In Block 77, the process alternates between, the first and second axes, e.g., the X and Y
axes. Each axis position is optimized alternately to ensure that an optimal position is maintained
35 for both axes. In Block 78 the optical element, e.g., the MEMS, is moved by a value of DELTA,

1 which is appropriately chosen for each axis according to the current position of the MEMS. In
one embodiment, the value of DELTA is determined from a function of the MEMS position and
an amount voltage used to move the MEMS, such that smaller values of DELTA are used for
5 larger MEMS voltages.

In Block 79 the process again samples the power output indicator and compares the result
with the initial or previous output power value. If the comparison indicates a greater output
power at the new position of the MEMS, the process replaces the x axis position in the lookup
10 table with the new position in Block 81. If the comparison indicates less output power at the new
position, the process commands the mirror to move to another position by a slight amount in a
direction opposite the previous direction. The process then samples the output power indicator
and compares the result with the initial result. If the comparison indicates a greater output power
15 at the new position, the process replaces the x axis position in the lookup table with the new
position in Block 701.

Blocks 77 through 81 are repeated for the y axis, with the offsets being in a second
direction and a direction opposition the second direction. The process then returns to Block 77,
20 unless Blocks 77 through 80 indicate a position of maximum power is attained. If the new
position results in a lower power, the direction of movement of the MEMS is reversed, e.g., by
changing the sign of DELTA, and repeating the loop. In Block 81, the initial position is
periodically updated in the lookup table using the current position.

25 In one embodiment, however, the process repeats until a new laser, or no laser, is
selected. Continually repeating the process is beneficial, for example, if thermal or other effects
result in displacement of some or all of the system components. In addition, at initial laser
selection, or whenever the wavelength of the laser is being adjusted, deviations in the outputs of
the photodetectors may be observed. Accordingly, in one embodiment mirror positioning is not
30 accomplished if the ratio of the photodetector signals is outside a predefined limit. In another
embodiment, mirror positioning as described above is first accomplished. Subsequently, the
wavelength of the laser is adjusted and deviations in the outputs of the photodetectors are
observed.

35 In yet a further embodiment, the amount of movement of the mirror during alignment is

1 reduced as the process repeats. This allows, for example, for finer adjustment of the mirror position over time, and also helps avoid limiting the mirror position to sub-optimal locations.

5 A flow diagram of another embodiment of the process for determining position of the mirror is provided in FIG. 8. In block 201 the process determines a selected laser based on a laser select command. In block 203 the process using a lookup table determines the expected or initial mirror positions for the selected laser. In block 205 the process determines if the laser/fiber coupling position should be optimized. It may be desirable to interrupt the optimization process
10 occasionally (i.e. when switching between lasers).

In block 207 the process samples the power output indicator and stores the result as an initial result.

15 In block 209 the optical element, e.g., the MEMS, is moved in a selected axis by a value of DELTA and the power output is sampled again. In block 211 the process calculates the slope of a power function by determining the change in the power output, i.e., the sampled power output in block 209 minus the initial result obtained in block 207, over the change in the position or location of the mirror in the first direction. In one embodiment, the MEMS position is updated and the MEMS is moved in block 214 by changing the current location by the calculated slope
20 multiplied by a change factor.

In Block 216, the initial position is periodically updated in the lookup table using the updated position of the MEMS determined in block 214. In Block 218, the process switches to the other axis, i.e., alternates between the X and Y axes. As such, each axis position is optimized
25 alternately to ensure the optimal position is maintained for both axes.

In one embodiment, however, the process repeats until a new laser, or no laser, is selected. In yet a further embodiment, the amount of movement of the mirror during alignment is reduced as the process repeats. This allows, for example, for finer adjustment of the mirror position over time, and also helps avoid limiting the mirror position to sub-optimal locations.
30

In another embodiment, predetermined positions of the mirror for the x and y axis and the power output of the laser selected are provided. In a further embodiment, the process determines the power output relative to positions in both the x and y axis. In either embodiment,
35 the process determines or approximates a power function that relates power output to the

1 positions of the mirror in the x and y axis.

For example, a tangent plane is determined in which the slope of the power function relative to the position of the mirror in the x direction and the slope of the power function relative to the position of the mirror in the y direction is determined for a specific position of the mirror in the x and y axis, i.e., the point of tangency of the function. From the calculated function a local maximum is determined, i.e., where the power output is greatest and is neither increasing or decreasing at a specific position of the mirror in the x and y axis. In other words, the derivative of the power function is 0 in every direction. In one embodiment, the local maximum determined is set as the initial start conditions or position of the mirror in the x and y axis in which maximum power output for the selected laser is obtained. The process in FIG. 7 is then used to confirm that this maximum power output point has not changed due to an error condition, such as movement of components of the package, thermal effects, etc.

A flow diagram of one embodiment of the process for determining position of the mirror using a quad detector is provided in FIG. 9. In block 301 the process determines a selected laser based on a laser select command. In block 303 the process samples the currents generated from each section A, B, C and D of the quad detector. In block 305 the process calculates ratios of the currents from of one section relative to another section. For example, in one embodiment, a first ratio (the current from section A over the current from section B) and a second ratio (the current from section C over the current from section D) are calculated. Various other embodiments of the first and second ratios, such as the current from section D over the current from section A, additional ratios, such as a third ratio (the current from section B over the section C) and any combination thereof may be provided.

In block 307 the process analyzes the ratios in relation to the position of the mirrors. In other words, if the process in block 307 determines that the first and second ratios are not equal to one, the process in block 309 moves the mirror using a control signal. If the first ratio is greater than one, the process moves the mirror along the x axis by a predetermined amount in a first direction. Alternatively, if the first ratio is less than one, the process moves the mirror along the x axis by a predetermined amount in a direction opposite of the first direction. If the first ratio is equal to one, but the second ratio is greater than one, then the process moves the mirror

1 along the x axis by a predetermined amount in a first direction. Alternatively, if the second ratio
is less than one, the process moves the mirror along the x axis by a predetermined amount in a
direction opposite of the first direction. The amount of movement is related to how much the
5 measured ratio is different from the ideal ratio. The process is then repeated continuing to block
303 sampling the currents from the quad detector. However, if in block 307 the process
determines that the first and second ratios are equal to one, the process ends. The process is also
repeated starting from block 303 for the y axis with the movement of the mirror along the y axis
10 being in a second direction and a direction which is opposite to the second direction. In one
embodiment, the ratio corresponds to a value determined during an initial calibration.

In one embodiment, however, the process repeats until a new laser, or no laser, is
selected. In yet a further embodiment, the amount of movement of the mirror during alignment
15 is reduced as the process repeats. This allows, for example, for finer adjustment of the mirror
position over time, and also helps avoid limiting the mirror position to suboptimal locations.

In one embodiment, initially, the process using a lookup table determines the expected
or initial mirror positions for the selected laser. This lookup table is generated specifically for
20 the device in an initial calibration procedure after the laser is packaged. In another embodiment,
a predetermined relationship between a section or sections of the quad detector and the position
of the MEMS structure is provided. For example, more light on section A and thus more current
from section A indicates that the mirror should be moved along the x axis in a first direction.
Using the first example and the first ratio describe above, the process then in block 307 would
25 recognize that the MEMS is to be moved in the first direction in block 309 if the first ratio is
greater than one. In another example, more light on section D and thus more current from section
D indicates that the mirror should be moved along the y axis in a second direction. Using this
example and the second ratio describe above, the process then in block 307 would recognize that
30 the MEMS is to be moved in the second direction in block 309 if the second ratio is less than
one. As such, in this embodiment, if a relationship between the currents from the sections and
the movement of the MEMS for the x and y axis is predetermined, the process does not need to
be repeated for the y axis.

35 A schematic for one embodiment of two axis control of an optical apparatus 91 is shown

1 in FIG. 10. The optical system has two controls to maintain coupling, labeled X and Y on the
diagram. The controls correspond to an electronic control of position, such as described in
reference to the previous figure. For example, the x-control determines the rotation of a tilt
5 mirror in the x-axis, while the y-control determines the rotation of the tilt mirror in the y-axis.

As illustrated in FIG. 10, an optical output of the unit is coupled to a fiber 93. Some of
the power is monitored through a tap 95 provides a signal to a photodetector 97. The higher the
10 coupled optical power, the greater the signal produced by the photodetector. The electrical signal
produced by the photodetector is provided to two phase lock loops or lock-in amplifiers 99a and
99b. These measure the sinusoidal components present in an input signal at a frequency
corresponding to a reference input signal and generate a signal whose magnitude corresponds to
15 the in-phase component of the input signal compared to the reference input signal. For example,
if the sinusoidal component of the input signal is in phase with the reference signal, an in-phase
output of the lock-in amplifier would be positive, while if the input signal is out-of-phase with
the reference signal, the in-phase output would be negative.

20 The output of the lock-in amplifier is then provided to a respective variable signal source
901a and/or 901b, where it is integrated to generate a DC signal. The DC signal is added to a
sinusoidal AC source 903a and/or 903b, and the combination is fed to the appropriate control
input of the optical system.

25 For two axis control, the AC sources for the x and y axes operate at two different
frequencies f_1 and f_2 . If the positive cycle of the dithering AC signal improves the optical
coupling, then the DC signal will increase to improve the output power, while if the positive
cycle reduces the coupling, then the DC signal will decrease. The operation of such a control
loop falls under the domain of feedback analysis, and the timing and stability can be easily
30 calculated. Additionally, the DC signals in various embodiments, are used to monitor the
degradation of the package's fiber coupling and/or be used to warn of an impending failure. This
is in contrast to conventional monitor photodiodes in laser packages which monitor only the
health of the laser chip itself and not the fiber coupled power, which requires a costly external
35 tap.

1 For telecom applications, such dithered signals may not be an important issue. For
example, in 2.5Gb/s communications (OC48), the communication link generally has a low-pass
cut-off of about 70MHz. Thus low frequency oscillations on the output signal should not lead
5 to significant errors in the data communication. Since the timing for the servo loop is ultimately
limited by the mechanical time constants of the transducer, the dithering frequencies and the
response time of the loop is far slower than the low pass cut-off frequency.

10 An alternative method of dithering that does not depend on phase locked loops or two
different dithering frequencies, as described above, is to directly tilt the beam in other directions
and monitor improvements or changes in fiber coupled power. For example, if the lookup table
indicates that previously the optical position for the mirror was at an x voltage of 100V and a y
voltage of 50 volts, the microprocessor determines and utilizes five points (100,50), (100.1, 50),
15 (99.9, 50), (100,50.1), and (100, 49.9), and then takes the point with the highest power for the
next iteration. In one embodiment, the alternative method is performed by a fast microprocessor
in a telecommunication system having a good signal to noise ratio.

20 However, in many applications, having a dithered signal on the output is not acceptable,
or splicing an appropriate tap on the output fiber may be prohibitive. In such cases an alternate
method of generating an error signal for the control loop is used. One method is described
below in reference to one embodiment of a fiber arrangement shown in FIG. 11. In place of a
standard cleaved fiber, a chiseled fiber is used. Such fibers are readily built by a number of
suppliers. The fiber 105 has a flat section where a single mode region is contained, but has
25 sloping sidewalls. When the light is focused by lens 101 on the core, some of the light at the
edges of the beam is incident on the sloping sidewalls and is reflected around the fiber. There
are four photodetectors placed on the periphery of the fiber, photodetector 103A is above the
fiber, 103B below, 103C to the right and 103D to the left.

30 In the initial packaging stage, the electronic control is varied to optimize the coupling to
the fiber. When this optimal packaging condition is achieved, the ratio of the optical power
falling on the vertical detectors (power incident on photodetector 103A divided by the power
falling on photodetector 103B) and on the horizontal detectors (power on the photodetector 103C
35 divided by the power falling on the photodetector 103D) is measured and the value stored. An

1 electronic control loop, such as that described in FIG. 9, is then configured to maintain these ratios during the operation of the device.

5 For example, if a different laser is selected, the electronic control loop adjusts to once again achieve these ratios. By using two photodetectors for each axis, an error signal independent of the optical power can be obtained. In another embodiment, three photodetectors are used along with a more complex control circuitry. For example, in FIG. 11, photodetector 103A can be left out. Lateral control is achieved by adjusting the ratio between the detected signal from photodetectors 103C and 103D, while vertical control is achieved by adjusting the ratio between a detected signal at photodetector 103B and the sum of detected signals from photodetectors 103C and 103D. The embodiment of FIG. 11 can also be combined with the dither approach mentioned previously, with in varying embodiments differing numbers of detectors being used. In one embodiment, a single detector provides an adequate feedback signal, with maximum coupling to the fiber occurring when the least amount of light hits the sloped sides and scatters out. As such, with a single detector, by minimizing the amount of scattered light, maximum coupling to the fiber can be achieved.

20 An alternative approach to using a chiseled lens is shown in FIG. 12. For most fiber coupling applications where minimal feedback is required for both the active component (such as a DFB laser) or for the system, an angle cleaved fiber is used. When the light is focused on the fiber, there is a parasitic reflection from the cleave. The reflection is refocused on a position-sensitive or a quad detector that will produce an error signal. Like the previous embodiment shown in FIG. 11, the relative ratios of light on the detectors, or the signal corresponding to the position can be stored as an initial calibration. Any offset from the initial calibration is detected by the electronics and fed back into the control loop. In FIG. 12, light is focused by lens 101 onto the facet of an angle cleaved fiber 113. The image on the cleave is then refocused by a second lens 115 onto a quad detector 117. This generates photocurrent in the four sections, labeled A, B, C, and D. The ratio of these currents are stored and used for maintaining alignment, as previously described with reference to the photodetectors in FIG. 11.

35 If the quad or position-sensitive detector is placed very close to the fiber, then the second refocusing lens 115 can be eliminated, as any shift in the position of the image on the fiber will

1 translate to varying detected powers on the photodetector. The same concept can be applied to
coupling to other structures. For example, when coupling a laser to a lithium niobate chip, the
position of the reflection from the facet can also be monitored.

5 In one embodiment, a beam splitter is placed before the optical fiber to independently
generate a second image. This is shown schematically in FIG. 13. The focusing lens 101 images
light onto the end face of a fiber 123. Between the lens and the fiber is a beamsplitter 121, which
forms a secondary image on a quad or position-sensitive detector 125. Once again, the ratio of
10 generated photocurrent in the detectors is stored during an initial calibration process, and an
electronic feedback system maintains this ratio continuously during the operation of the device.

In general, any optical system will have a set of parasitic reflections, and these can also
be used to maintain optimal coupling to the fiber. FIG. 14 shows that a reflection from the back
15 side of the movable mirror forms a secondary image next to the fiber if the mirror is not perfectly
parallel. One could also consider the front side reflection as parasitic, and the backside reflection
as the main beam, depending on how the mirror is coated. The light beam from the laser element
7 via lens 81 reflects both from a front face of the mirror 133 and also from a back face 135. The
20 image from the front face is focused on a fiber 15 via lens 805, while the image from the back
face will occur slightly displaced from the main image. A quad or position-sensitive detector 131
is placed at this secondary image to lock the main image on the fiber, as previously described.
In various other embodiments, other parasitic images are used, such as a reflection from other
optical elements, for example, the exit window at one end of the package, or the light transmitted
25 through the mirror which shifts as a function of mirror position.

For optical systems with laser arrays, as described in the figures, whenever a particular
laser needs to be coupled to the fiber, the laser on one side of the active device is also activated,
though perhaps at a lower output power. This adjacent laser source produces an adjacent image
30 next to the fiber core. The relative position depends on the spacing in the array and the
magnification of the optical system. Since the beam from this laser is not needed in the fiber, a
quad detector or a position-sensitive detector is used to detect the position of the adjacent image.
As previously described, an error signal is generated by measuring the ratio of photocurrents in
the quad detector. However, in using this technique, an additional laser is utilized and extra
35

1 power is consumed for this additional "guide" laser. This embodiment is described in further detail in reference to FIG. 15.

5 The multi-element laser array 5 contains lasers of different characteristics. A particular laser, e.g., laser element 2, is selected to be coupled into the fiber 15. An adjacent laser, e.g., laser element 143, is also activated, and the beam from the adjacent laser propagates through the optical system, i.e., via lens 81, mirror 145, and lens 805, and is focused adjacent to the fiber. A position sensitive detector 141 detects the location of the adjacent image or guiding spot to
10 generate the error or feedback signal. In other embodiments, instead of the adjacent laser being used, others lasers, a given distance away from the selected laser, are used. Using a larger separation between the "active" laser and the "guide" laser can be helpful, as the image is further from the fiber core and thus easier to capture from a photodetector. However, a number of lasers on the chip may be required. For example, if twelve lasers are used and a third laser away from
15 a selected laser along one direction of the laser array is used to monitor the fiber coupling, then fifteen lasers in total would be used on the chip.

Accordingly, the present invention provides a system and methodology for controlling
20 fiber coupling between tunable lasers and an optical output to maximize fiber coupled power. Although this invention has been described in certain specific embodiments, many additional modifications and variations would be apparent to one skilled in the art. It is therefore to be understood that this invention may be practiced otherwise than is specifically described. Thus, the present embodiments of the invention should be considered in all respects as illustrative and
25 not restrictive. The scope of the invention to be indicated by the appended claims, their equivalents, and claims supported by this specification rather than the foregoing description.

1
CLAIMS:

5
1. An optical transmission method comprising:
selecting a laser from an array of lasers, each laser emitting light at differing
wavelengths;
establishing an optical path from the laser to an optical output, such that light from the
laser is transmitted into an optical output; and
adjusting the optical path to maximize output power of the emitted light at the optical
10 output.

15
2. The method of claim 1 wherein selecting a laser comprises:
receiving an indication of a desired wavelength;
choosing a laser from the array of lasers that has the desired wavelength; and
causing the chosen laser to emit light.

20
3. The method of claim 1 wherein establishing an optical path further comprises
determining a position that causes an optical element to direct light from the selected
laser to the optical output; and
placing the optical element in the determined position.

25
4. The method of claim 3 further comprising:
measuring output power of the emitted light at the optical output; and
determining an expected output power that corresponds to the selected laser.

30
5. The method of claim 4 wherein determining an expected output power
comprises:
establishing a lookup table, the table having entries in which individual lasers in the
laser array are each assigned an output power value; and
identifying an entry in the lookup table that corresponds to the selected laser.
35

1 6. The method of claim 4 wherein adjusting the optical path is based on a
comparison of the measured output power to the determined expected output power.

5 7. The method of claim 4 further comprising generating an adjustment signal
based on the comparison of the measured output power and the predetermined output power.

10 8. The method of claim 7 further comprising determining a movement direction
based on the adjustment signal.

15 9. The method of claim 4 wherein adjusting the optical path is based on a
comparison of the measured output power to the determined expected output power.

20 10. The method of claim 7 wherein adjusting the optical path further comprises
moving the optical element in a first direction based on the adjustment signal.

25 11. The method of claim 4 further comprising:
generating a power line, the power line representing a functional relationship of output
power and positions of the optical element; and
determining a slope of the power line.

30 12. The method of claim 11 wherein adjusting the optical path further comprises
moving the optical element in a first direction based on the slope.

35 13. The method of claim 12 wherein adjusting the optical path further comprises
moving the optical element in a second direction based on the slope, the second direction
being substantially opposite from the first direction.

40 14. The method of claim 11 wherein adjusting the optical path further comprises
moving the optical element in a first direction when the slope is positive.

1
15. The method of claim 14 wherein adjusting the optical path further comprises
moving the optical element in a second direction when the slope is negative, the second
5 direction being substantially opposite from the first direction.

16. The method of claim 11 further comprising determining a local minima of the
power line.

10
17. The method of claim 16 wherein adjusting the optical path further comprises
moving the optical element when the measured output power differs from the local minima.

15
18. The method of claim 4 further comprising:
determining a power function that relates output power and positions of the optical
element along a plurality of axes; and
determining a derivative of the power function.

20
19. The method of claim 18 wherein adjusting the optical path further comprises
moving the optical element when the derivative is positive in a first direction along one of the
plurality of axes.

25
20. The method of claim 19 wherein adjusting the optical path further comprises
moving the optical element when the derivative is negative in a second direction along one of
the plurality of axes, the second direction being a direction substantially opposite of the first
direction.

30
21. The method of claim 4 wherein measuring the output power further comprises:
measuring the output power at a first photodetector proximate the optical output; and
measuring the output power at a second photodetector proximate the optical output.

1
22. The method of claim 21 further comprising determining a power ratio of the measured output power at the first photodetector and the measured output power at the second photodetector.

5
23. The method of claim 22 wherein adjusting the optical path further comprise moving the optical element in a first direction if the power ratio is less then a predefined limit.

10
24. The method of claim 21 further comprising summing together the measured output power at the first photodetector and the measured output power at the second photodetector.

15
25. The method of claim 24 wherein adjusting the optical path further comprises moving the optical element in a first direction if the summed output power is less then a predetermined limit.

20
26. The method of claim 1 wherein measuring the output power comprises determining a location of light at a photodetector proximate the optical output.

25
27. The method of claim 24 wherein adjusting the optical path further comprises moving the optical element in a first direction if the location of the light differs from predetermined location.

30
28. The method of claim 1 further comprises focusing the emitted light into the optical output by placing a lens in the established optical path.

29. The method of claim 1 wherein the optical output comprises a fiber.

35
30. The method of claim 4 wherein determining an expected output power

1 comprises:

establishing a lookup table, the table having entries in which individual lasers in the
laser array are each assigned a predetermined output power value and associated with a
5 predetermined location identified for the optical element; and
identifying an entry in the lookup table that corresponds to the selected laser.

31. The method of claim 30 wherein adjusting the optical path is based on a
10 comparison of the measured output power to the output power value for the selected laser and
a comparison of location of the optical element and the predetermined location for the optical
element for the selected laser.

32. The method of claim 30 wherein adjusting the optical path further comprises
15 moving the optical element based on the predetermined location for the optical element for
the selected laser and a current location of the optical element.

33. An optical transmission control apparatus comprising:
20 an array of lasers;
at least one optical element;
an optical output, such that light from a laser from the array of lasers is directed into
the optical output by the at least one optical element; and
25 a controller coupled to the at least one optical element and configured to adjust the at
least one optical element to maximize output power of the light directed into the optical
output.

34. The apparatus of claim 33 wherein the optical output comprises a first region
30 that reflects light emitted by a selected laser from the array of lasers.

35. The apparatus of claim 34 further comprising a plurality of photodetectors
35 proximate the optical output; and

1 wherein the controller is coupled to the plurality of photodetectors and configured to
adjust the at least one optical element based on the optical power determined by each
photodetector.

5 36. The apparatus of claim 34 further comprising a plurality of photodetectors
proximate the optical output; and

10 wherein the controller is coupled to the plurality of photodetectors and configured to
generate an error signal and to adjust the at least one optical element based on the generated
error signal.

15 37. The apparatus of claim 33 wherein the optical output comprises a chiseled
fiber.

20 38. The apparatus of claim 37 further comprising a plurality of photodetectors
located at a periphery of the chiseled fiber, each photodetector configured to receive light
reflected from the chiseled fiber and to determine an optical power of the received light at
each photodetector; and

25 wherein the controller is coupled to the plurality of photodetectors and configured to
adjust the at least one optical element based on the optical power determined by each
photodetector.

30 39. The apparatus of claim 33 further comprising a plurality of photodetectors
proximate the optical output; and

35 wherein the controller is coupled to the plurality of photodetectors and configured to
adjust the at least one optical element based on the optical power determined by each
photodetector.

40 40. The apparatus of claim 33 further comprising a plurality of photodetectors
proximate the optical output; and

1 wherein the controller is coupled to the plurality of photodetectors and configured to
generate an error signal and to adjust the at least one optical element based on the generated
error signal.

5 41. The apparatus of claim 40 wherein the error signal is based on a comparison of the
optical power determined and a predetermined set of optical power values.

10 42. The apparatus of claim 40 wherein the error signal is based on a location of
light detected by each of the plurality of photodetectors.

15 43. The apparatus of claim 33 further comprising:
a first detector, the first detector measuring output power at the first detector;
a second detector, the second detector measuring output power at the second detector;
and
wherein the controller determines a ratio of the measured output power at the first
20 detector versus the measured output power at the second detector and adjusts the at least one
optical element when the ratio is less than a predefined limit.

25 44. The apparatus of claim 33 further comprising:
a first detector, the first detector measuring output power at the first detector;
a second detector, the second detector measuring output power at the second detector;
and
wherein the controller sums the measured output power at the first detector with the
measured output power at the second detector and adjusts the at least one optical element
30 when the summed measured output powers exceeds a predetermined limit.

35 45. The apparatus of claim 33 further comprising:
a first detector, the first detector measuring output power at the first detector as a first
detected power;

1 a second detector, the second detector measuring output power at the second detector
as a second detected power;

5 a third detector, the third detector measuring output power at the third detector as a
third detected power; and

 a fourth detector, the fourth detector measuring output power at the fourth detector as
a fourth detected power.

10 46. The apparatus of claim 45 wherein the controller is configured to determine a
ratio of one of a first, second, third and fourth detected power versus a different one of a first,
second, third, and fourth detected power and to adjust the at least one optical element when
the ratio differs from a predetermined ratio.

15 47. The apparatus of claim 33 further comprising:

 a first detector, the first detector measuring output power at the first detector as a first
detected power;

20 a second detector, the second detector measuring output power at the second detector
as a second detected power; and

 a third detector, the third detector measuring output power at the third detector as a
third detected power.

25 48. The apparatus of claim 47 wherein the controller is configured to determine a
ratio of one of a first, second, and third detected power versus a different one of a first,
second, and third detected power and to adjust the at least one optical element when the ratio
differs from a predetermined ratio.

30 49. The apparatus of claim 33 further comprising a position detector proximate the
optical output and configured to determine a location of light incident on the position
detector.

1 50. The apparatus of claim 49 wherein the controller is configured to adjust the at least one optical element when the determined location differs from a predetermined location.

5 51. The apparatus of claim 33 further comprising a detector proximate the optical output and having a plurality of regions and configured to measure output power of light emitted from a selected laser that strikes each region.

10 52. The apparatus of claim 51 wherein the controller is configured to adjust the at least one optical element based on the output power measured at each region.

15 53. The apparatus of claim 33 further comprising:
a detector proximate the optical output and having a plurality of regions and configured to determine locations of light emitted from a selected laser that strikes the plurality of regions.

20 54. The apparatus of claim 53 wherein the controller is configured to adjust the at least one optical element based on the determined locations of light.

25 55. The apparatus of claim 33 wherein the optical output comprises an angled cleaved fiber.

30 56. The apparatus of claim 55 further comprising a detector proximate the optical output, such that the angled cleaved fiber reflects a portion of the light emitted from the laser to the detector.

35 57. The apparatus of claim 56 wherein the controller is coupled to the detector and is configured to adjust the at least one optical element based on location of the reflected portion of light incident upon the detector.

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58. The apparatus of claim 56 wherein the controller is coupled to the detector and
is configured to adjust the at least one optical element based on optical power measured by
the detector.

5
59. The apparatus of claim 56 further comprising a second lens that focuses the
reflected portion of light to the detector.

10
60. The apparatus of claim 33 further comprising a wavelength locker having a tap
coupled to the optical output; and
wherein the controller is configured to adjust the at least one optical element based on
output power of the light detected by the tap of the wavelength locker.

15
61. The apparatus of claim 33 further comprising a wavelength locker being in-
line with the optical output; and
wherein the controller is configured to adjust the at least one optical element based on
output power of the light detected by the wavelength locker.

20
62. The apparatus of claim 33 wherein the optical output comprises a fiber.

25
63. An optical transmission control apparatus comprising:
an array of lasers having lasers configured to emit light;
an optical output configured to receive light;
a detector near the optical output;
at least one optical element configured to receive light from a laser from the array of
30 lasers and to direct a portion of the light to the optical output and a portion of the light to the
detector; and
a controller being coupled to the at least one optical element and configured to adjust
the at least one optical element to maximize output power of the light directed into the optical
35 output.

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64. The apparatus of claim 63 wherein the controller is coupled to the detector and
is configured to adjust the at least one optical element based on location of the portion of light
5 incident upon the detector.

65. The apparatus of claim 63 wherein the controller is coupled to the detector and
is configured to adjust the at least one optical element based on optical power of the portion
10 of light measured by the detector.

66. The apparatus of claim 63 wherein the portion of light directed to optical
output has a greater optical power than the portion of the light directed to the detector.
15

67. The apparatus of claim 63 wherein the at least one optical element comprises a
beam splitter.

68. The apparatus of claim 63 wherein the at least one optical element comprises a
20 mirror.

69. The apparatus of claim 68 wherein the mirror has a front face and a back face,
the front face reflecting light to the optical output and the back face reflecting light to the
25 detector.

70. The apparatus of claim 68 wherein the mirror has a front face and a back face;
the front face reflecting light to the detector and the back face reflecting light to the optical
30 output.

71. An optical transmission control apparatus comprising:
an array of lasers comprising a first laser and a second laser, the first laser configured
35 to emit light and the second laser configured to emit light;

1
an optical output configured to receive light from the first laser;
a detector near the optical output and configured to receive light from the second
laser;
5 at least one optical element configured to receive light from the first and second
lasers; and
a controller being coupled to the at least one optical element and configured to adjust
the at least one optical element to maximize output power of the light received by the optical
10 output.

72. The apparatus of claim 71 wherein the controller is coupled to the detector and
is configured to adjust the at least one optical element based on location of the light received
15 by the detector.

73. The apparatus of claim 71 wherein the controller is coupled to the detector and
is configured to adjust the at least one optical element based on optical power of the light
20 received by the detector.

74. The apparatus of claim 71 wherein the second laser is adjacent to the first
laser.

75. The apparatus of claim 71 wherein the second laser is a predetermined
distance from the first laser.

76. The apparatus of claim 75 wherein the predetermined distance is based on
30 spacing of the lasers in the array and total distance of an optical path of light emitted from a
laser of the array of lasers to the optical output.

77. The apparatus of claim 75 wherein the predetermined distance is proportional
35 to a distance from the optical output to the photodetector.

1
78. The apparatus of claim 71 wherein the first laser is a laser having a wavelength
that corresponds to a desired wavelength.

5
79. The apparatus of claim 71 wherein the first laser is configured to produce an
image that is received by the detector, and the controller is configured to adjust the at least
one optical element based on location of the image received by the detector.

10
80. An optical transmission control apparatus comprising:
emitting means for emitting light having different wavelengths;
output means;
15 optical means for directing light having a particular wavelength from the emitting
means into the output means; and
control means coupled to the optical means and for adjusting the optical means to
maximize output power of the light directed into the output means.

20
81. The apparatus of claim 80 further comprising reflective means for reflecting
light from the emitting means and directed to the output means.

25
82. The apparatus of claim 81 further comprising sensing means for sensing light
and is proximate the output means; and
wherein the control means is coupled to the sensing means and adjusts the optical
means based on light sensed by the sensing means.

30
83. The apparatus of claim 82 wherein the control means is coupled to the sensing
means and generates an error signal to adjust the optical means based on the generated error
signal.

35
84. The apparatus of claim 83 wherein the error signal is based on a comparison of

1 optical power determined by the sensing means and predetermined optical power values.

5 85. The apparatus of claim 83 wherein the error signal is based on a location of light detected by the sensing means.

10 86. The apparatus of claim 83 wherein the error signal is based on ratios of measured output power sensed by the sensing means and the control means adjusts the optical means when the ratios are less than a predefined limit.

15 87. The apparatus of claim 83 wherein the error signal is based on addition of measured output power by the sensing means and the control means adjusts the optical means when the measured output power added together exceeds a predetermined limit.

20 88. The apparatus of claim 83 wherein the error signal is based on ratios of measured output power sensed by the sensing means and the control means adjusts the optical means when the ratios differ from predefined ratios.

25 89. The apparatus of claim 82 wherein the control means is configured to adjust the optical means when the determined location of the optical means differs from a predetermined location.

90. The apparatus of claim 82 wherein the optical means directs a portion of light from the emitting means to the sensing means.

30 91. The apparatus of claim 90 wherein the control means is coupled to the sensing means and adjusts the optical means based on location of the portion of light incident upon the sensing means.

35 92. The apparatus of claim 90 the control means is coupled to the sensing means

1 and adjusts the optical means based on optical power of the portion of light measured by the sensing means.

5 93. The apparatus of claim 90 wherein the optical means comprises a beam splitter.

10 94. An optical transmission control apparatus comprising:
a laser emitting light
an optical fiber;
optical means for directing the light from the laser into a pathway directed to the fiber;
and
15 control means, coupled to the optical means, for adjusting the optical means to maximize output power of the light directed into the pathway directed to the fiber.

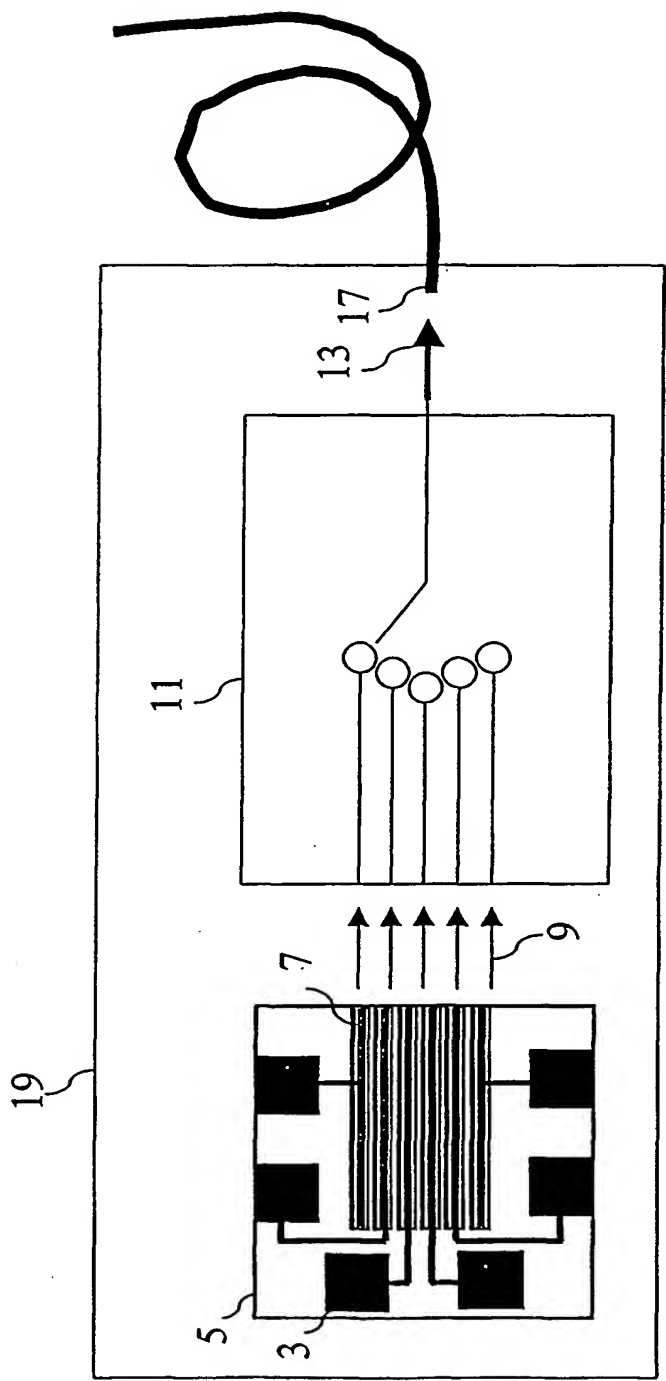


FIG. 1

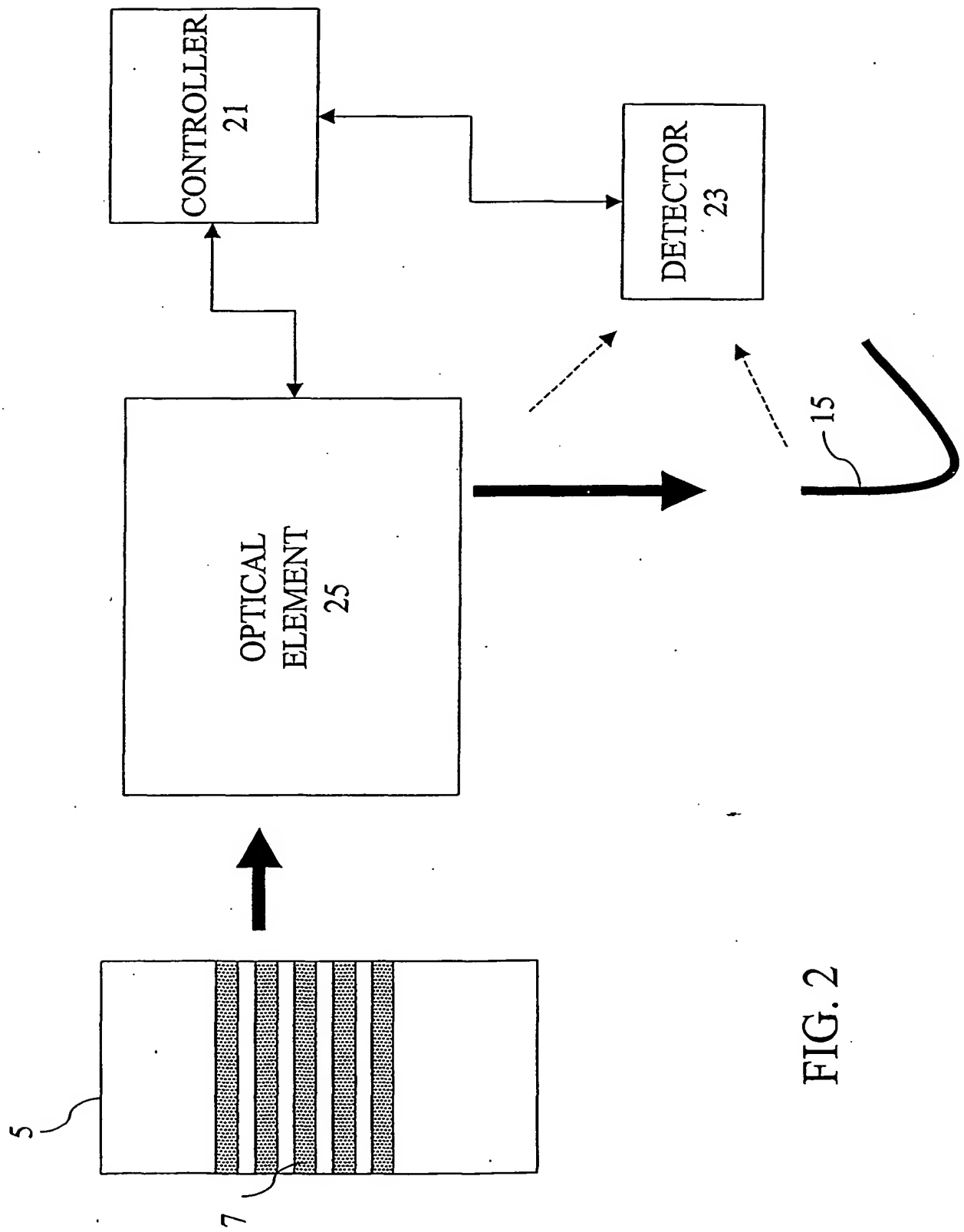


FIG. 2

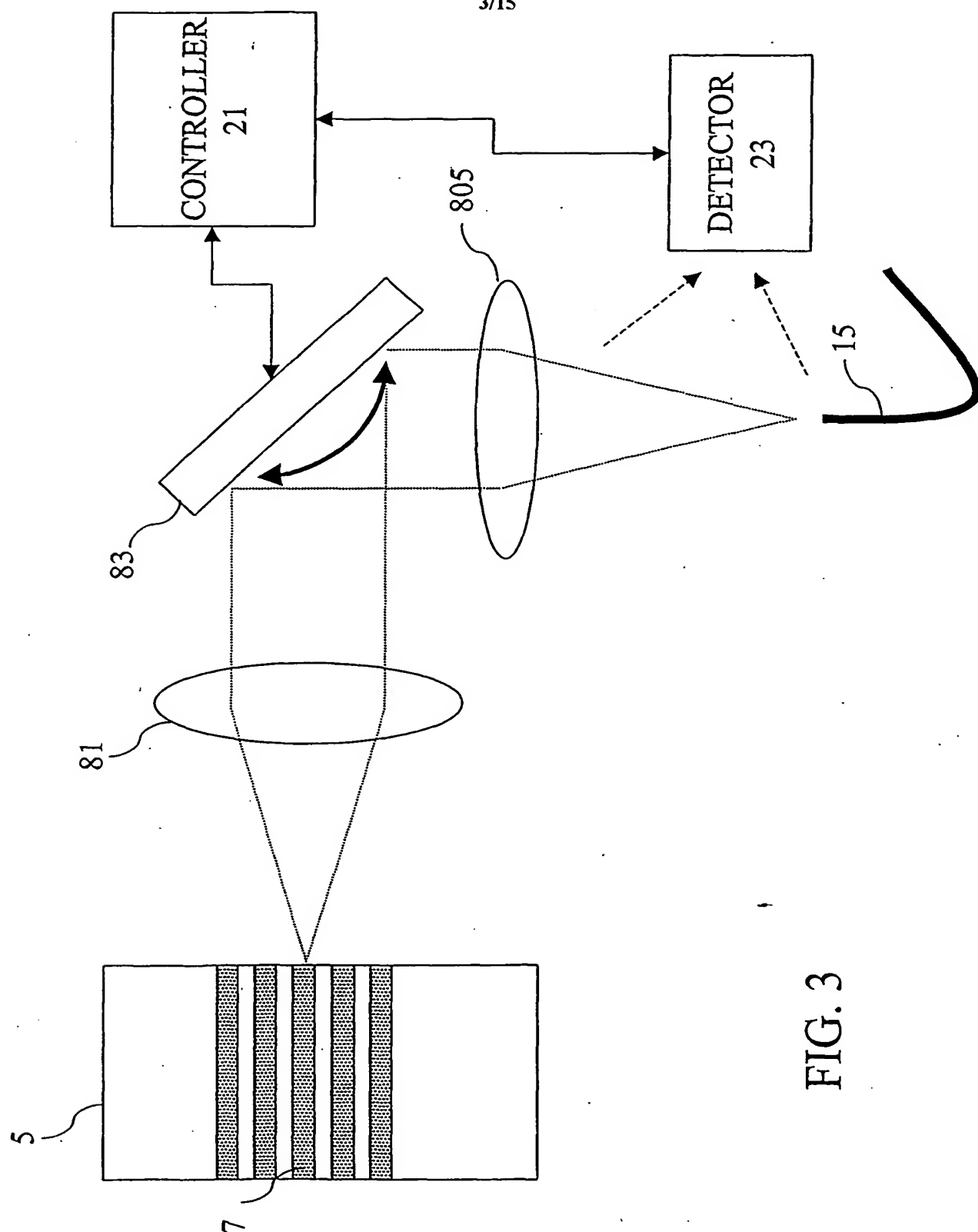
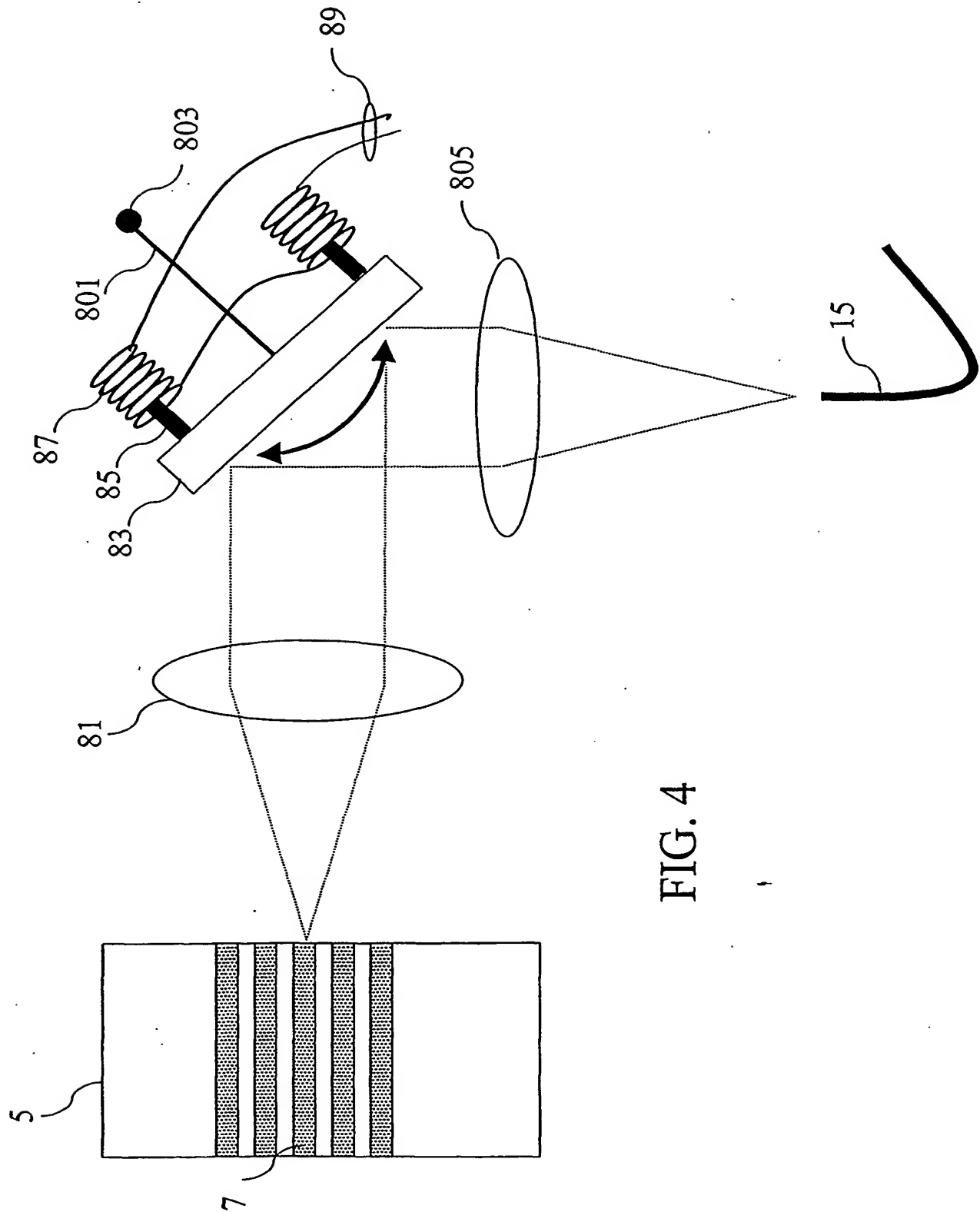


FIG. 3



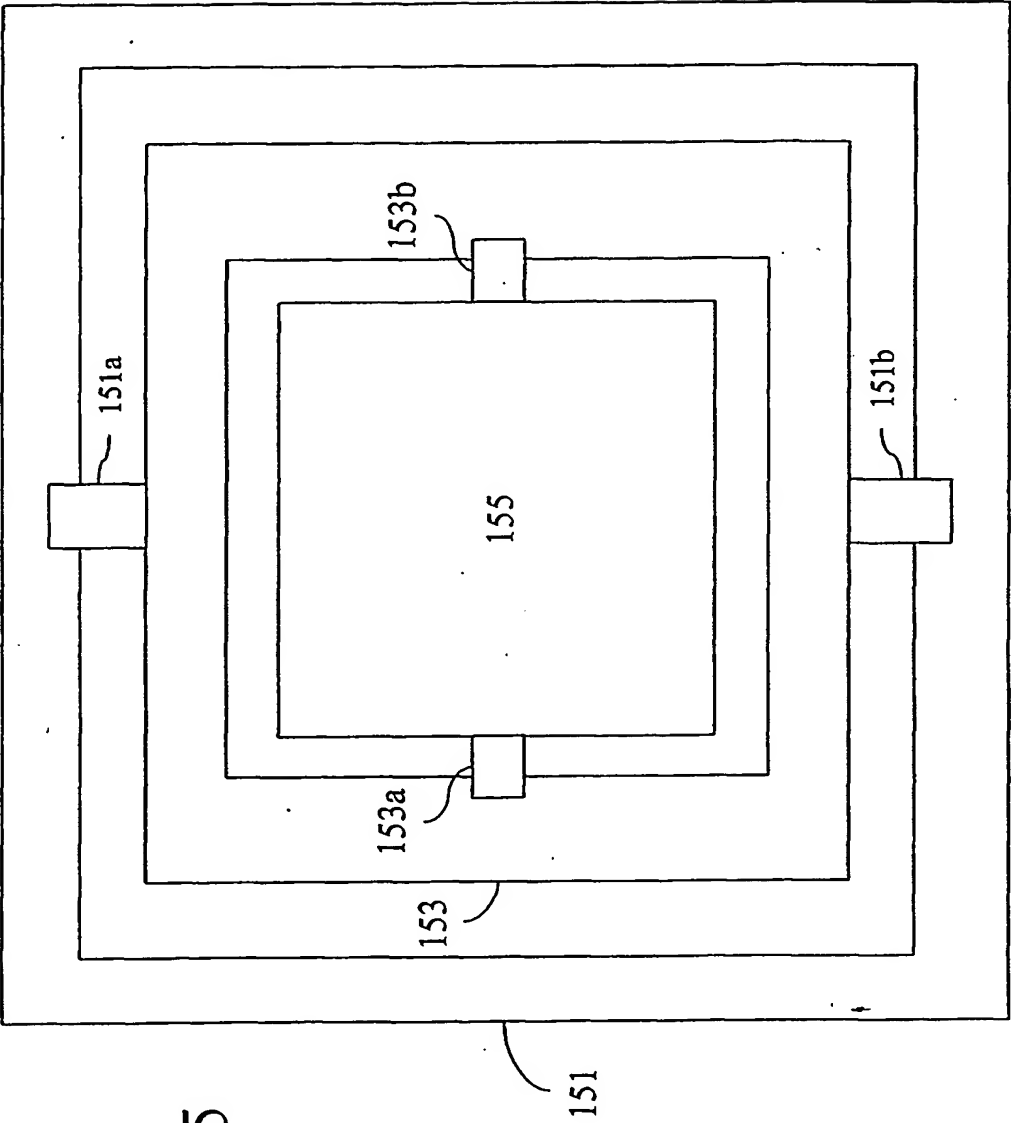


FIG. 5

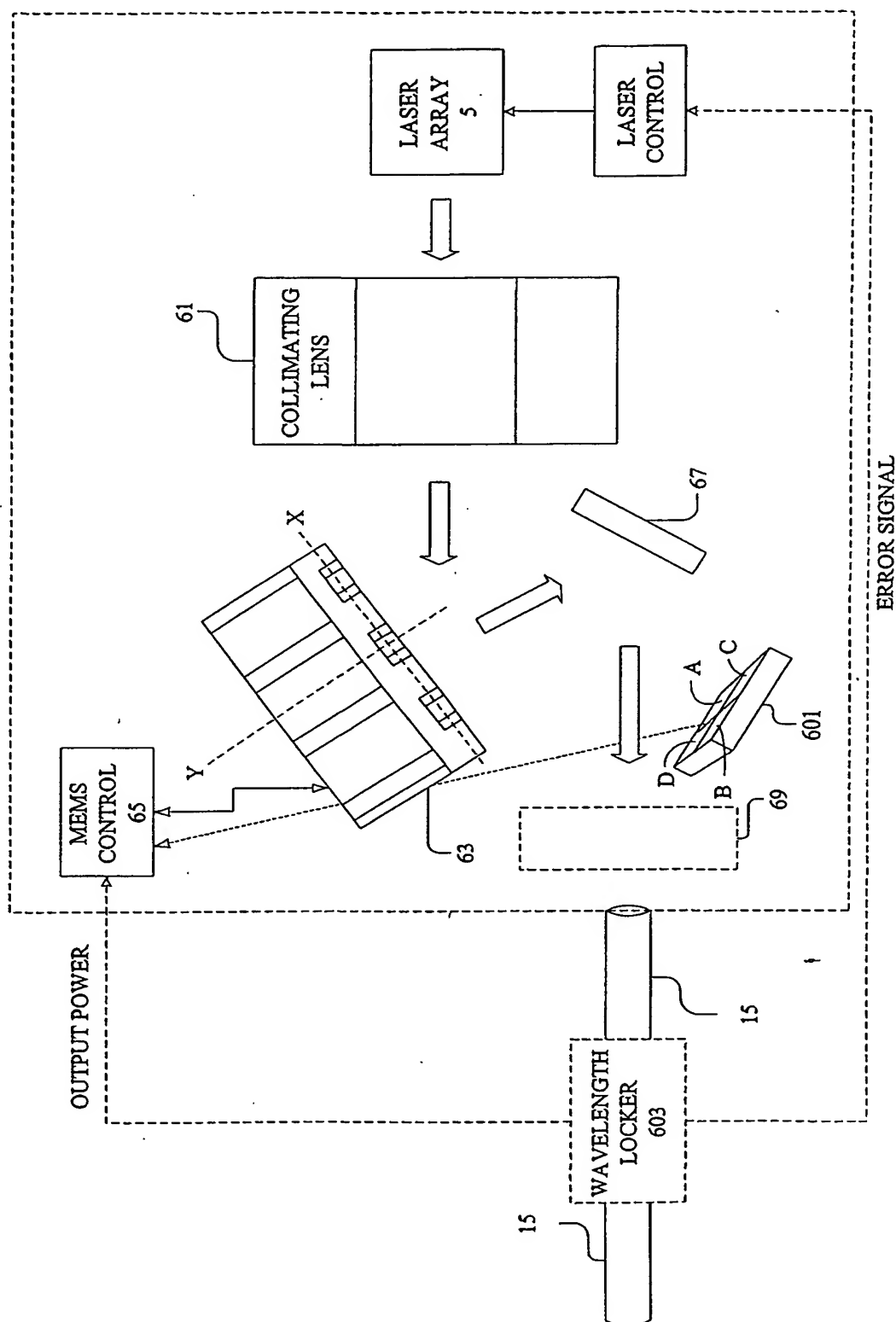


FIG. 6

FIG. 7

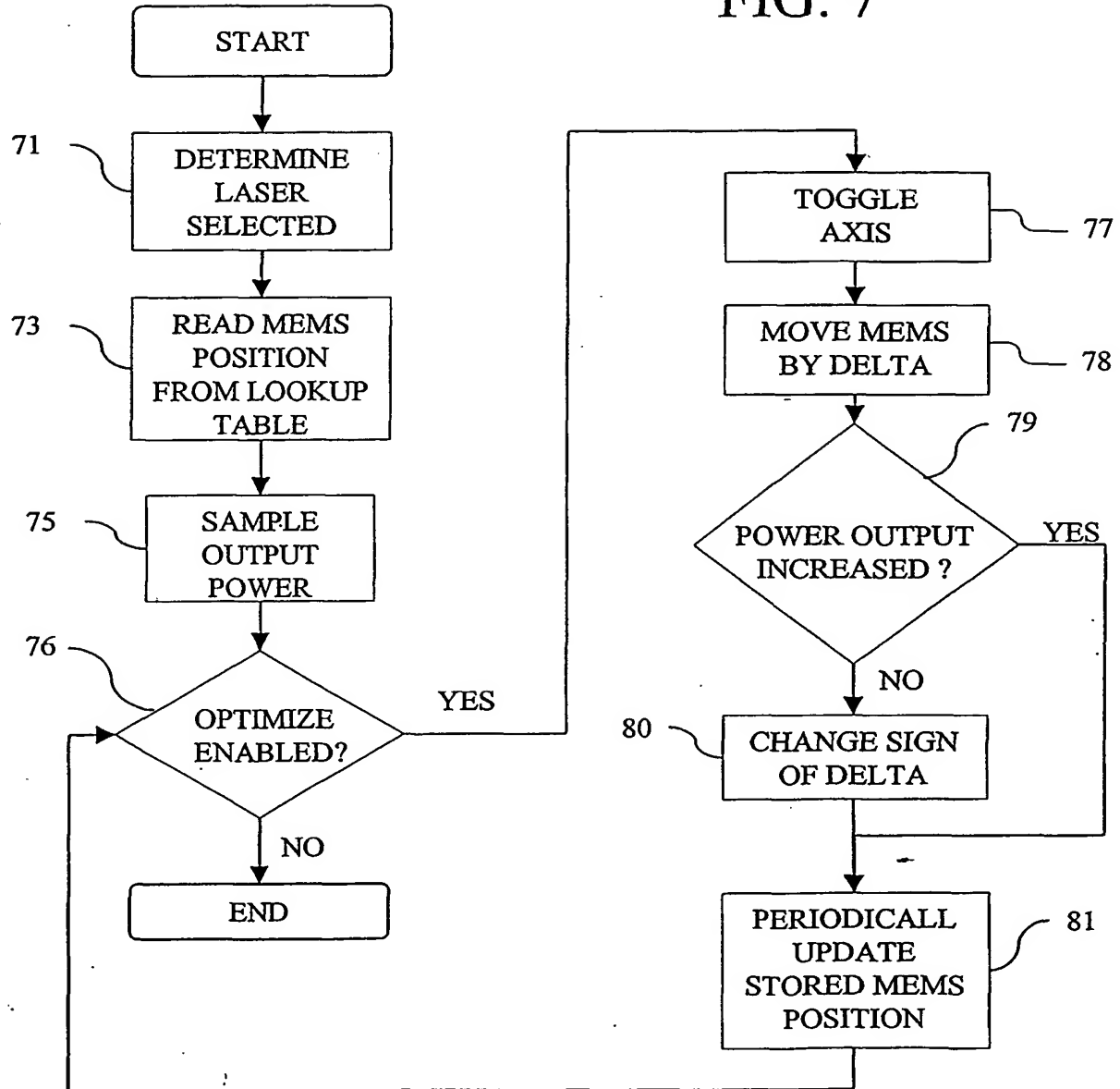


FIG. 8

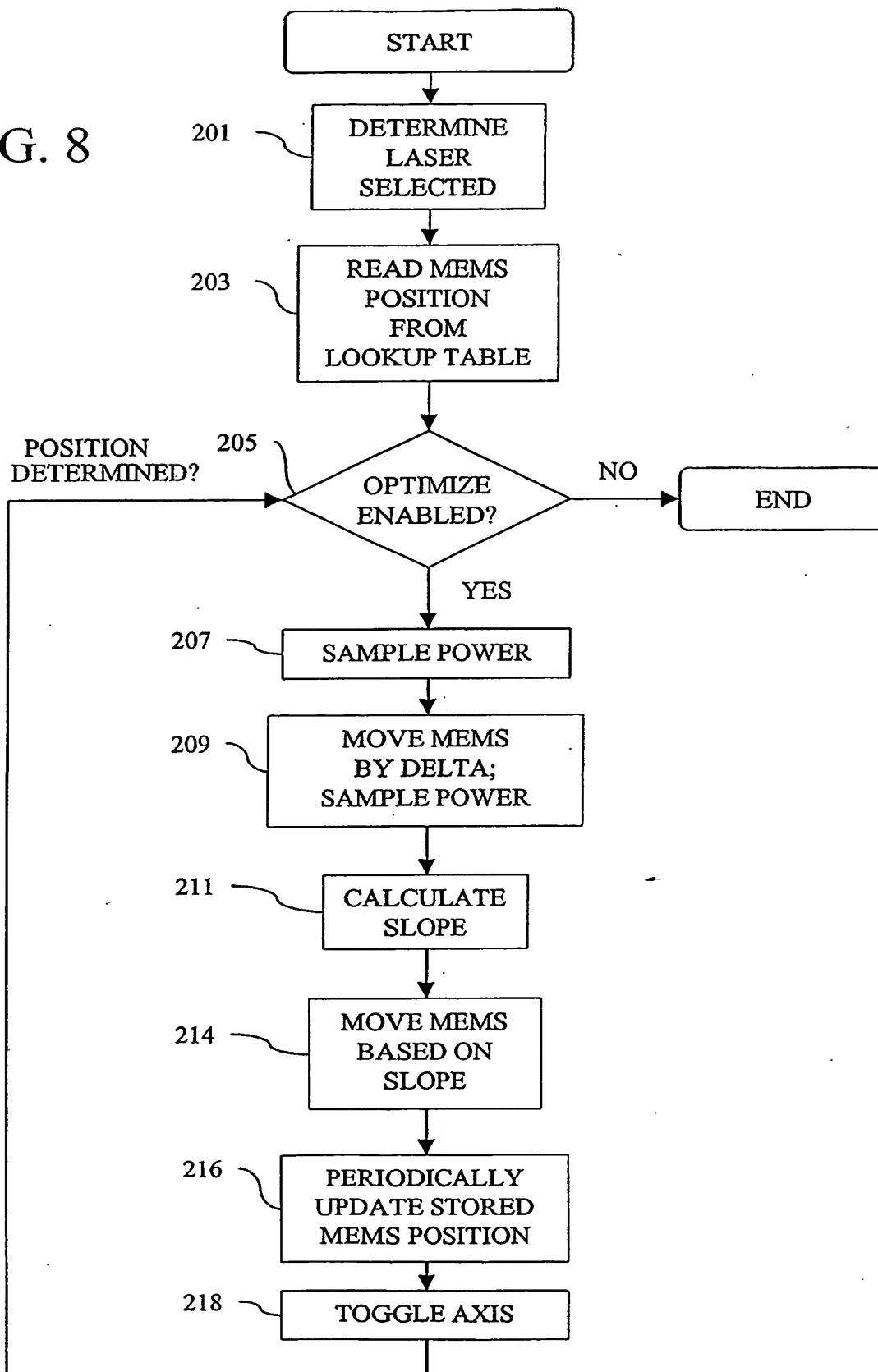
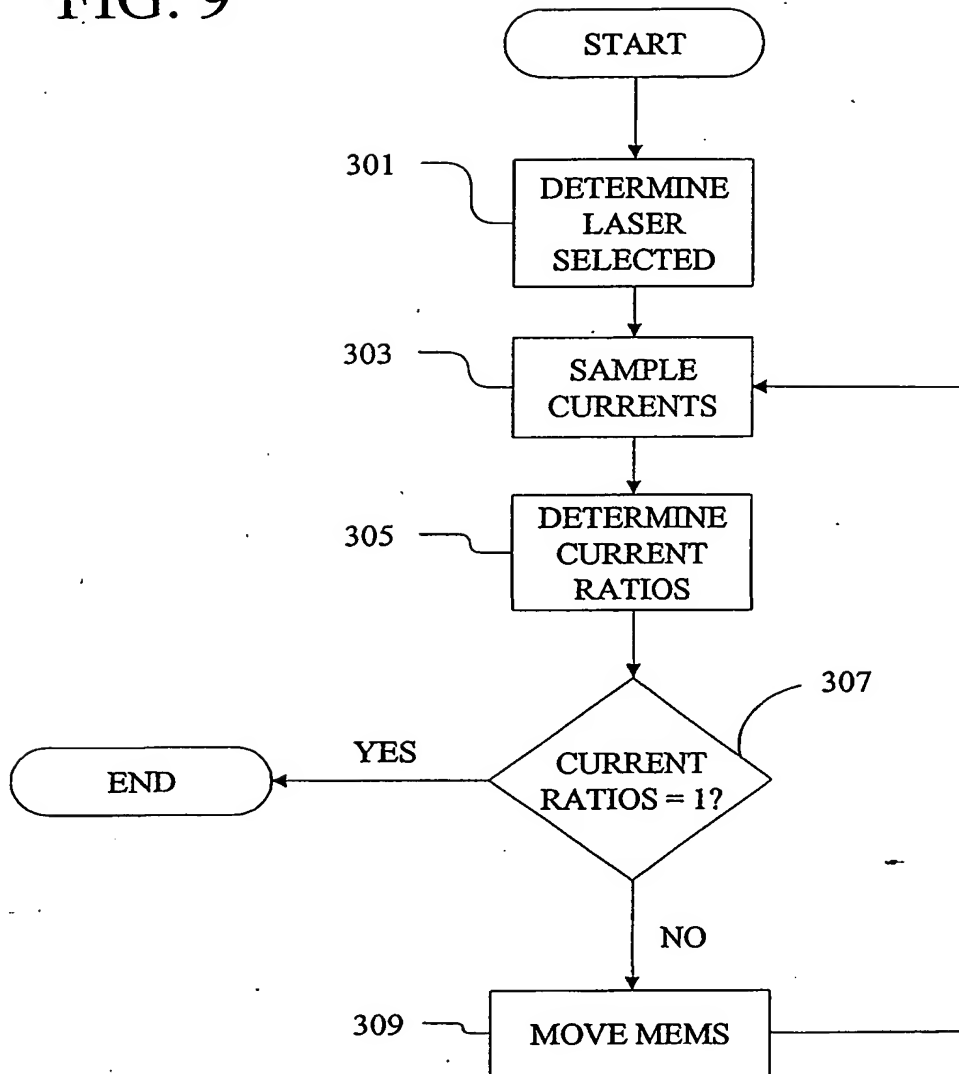


FIG. 9



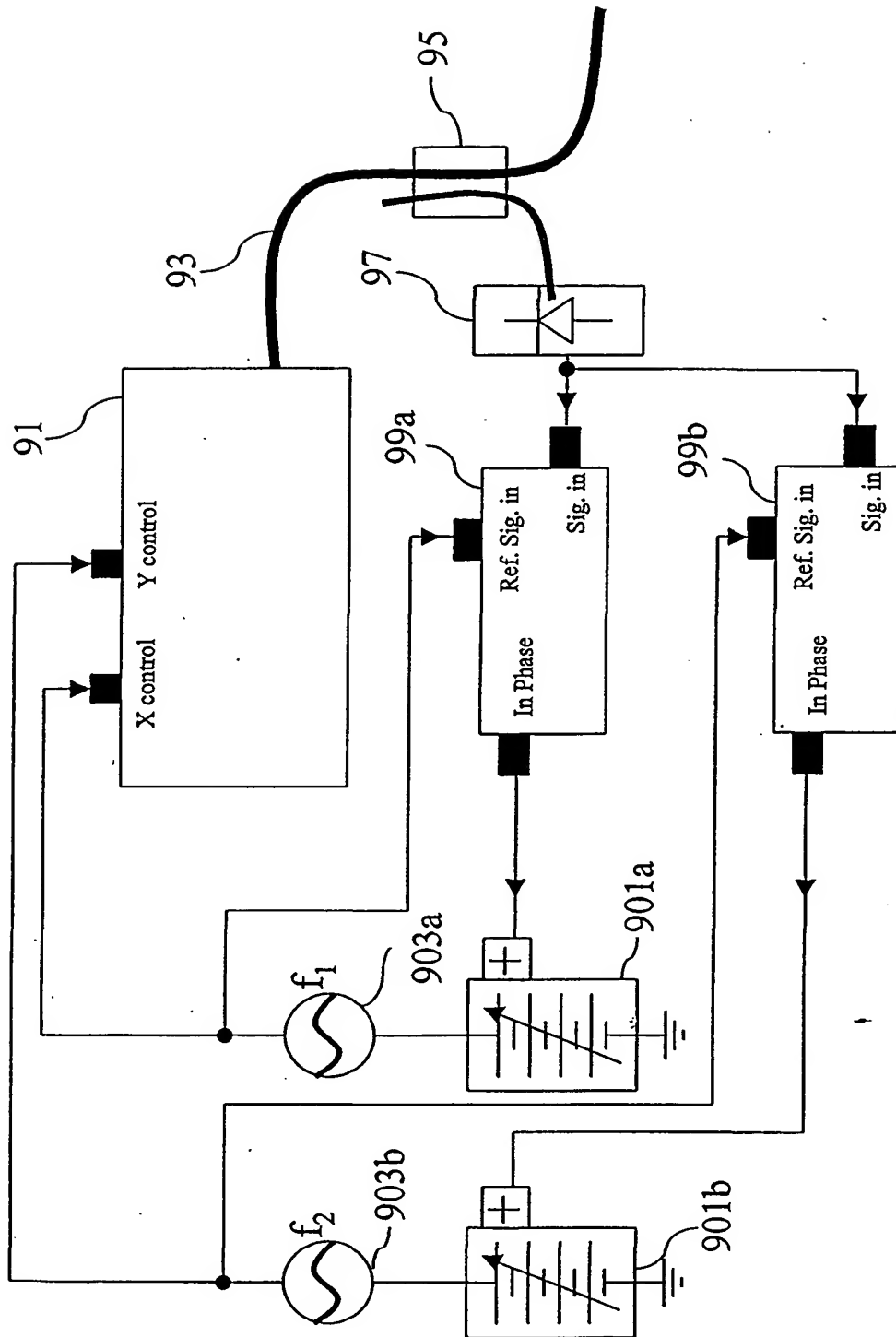


FIG. 10

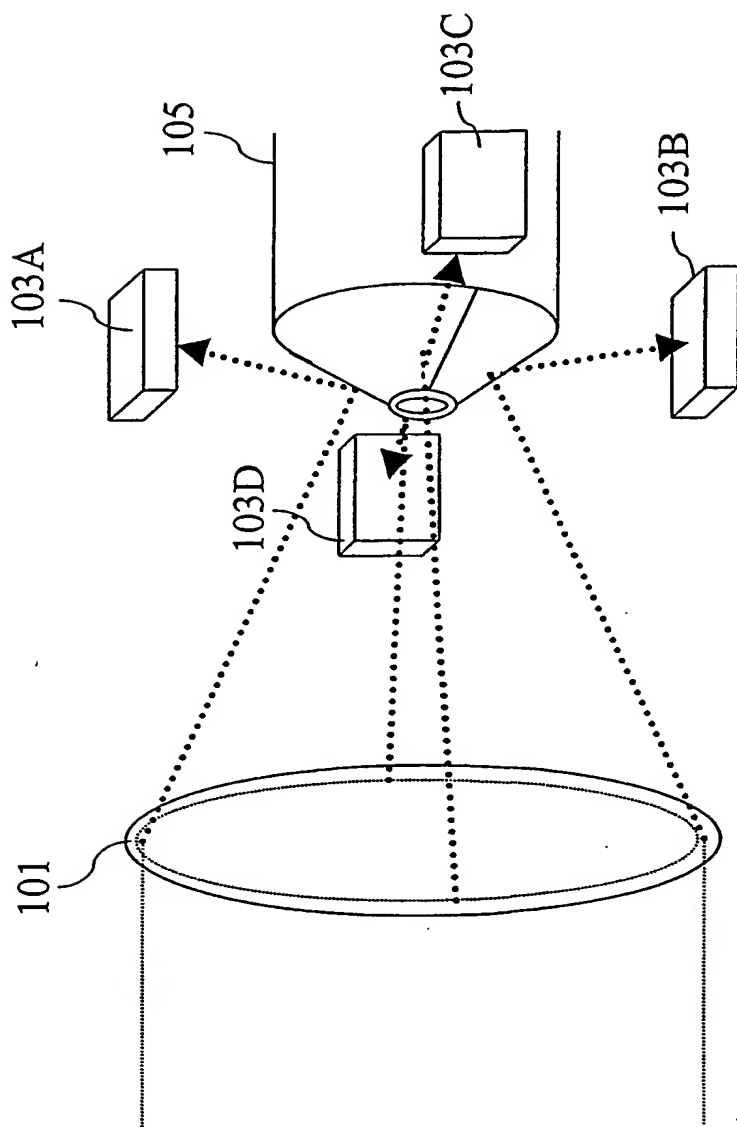


FIG. 11

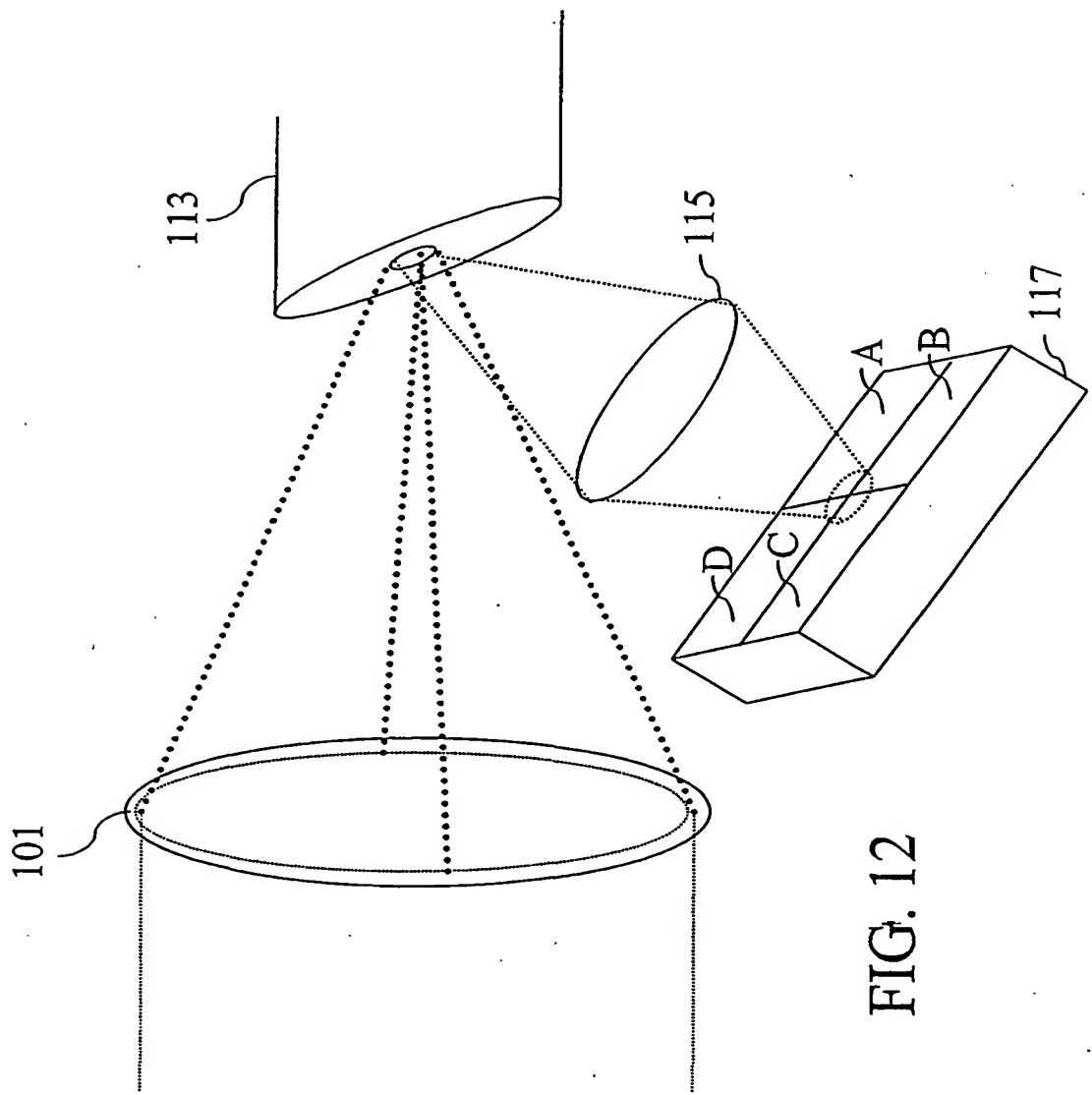


FIG. 12

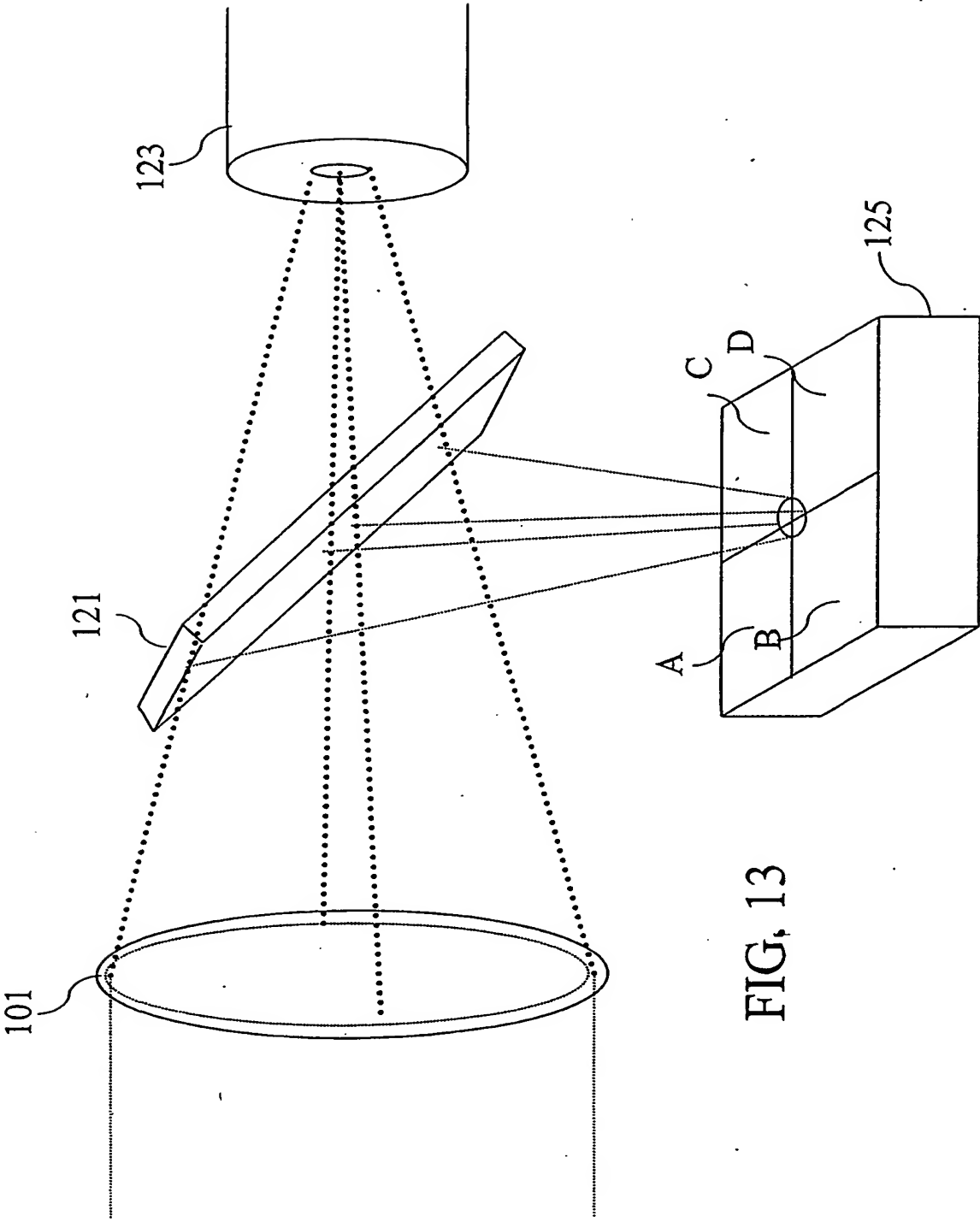


FIG. 13

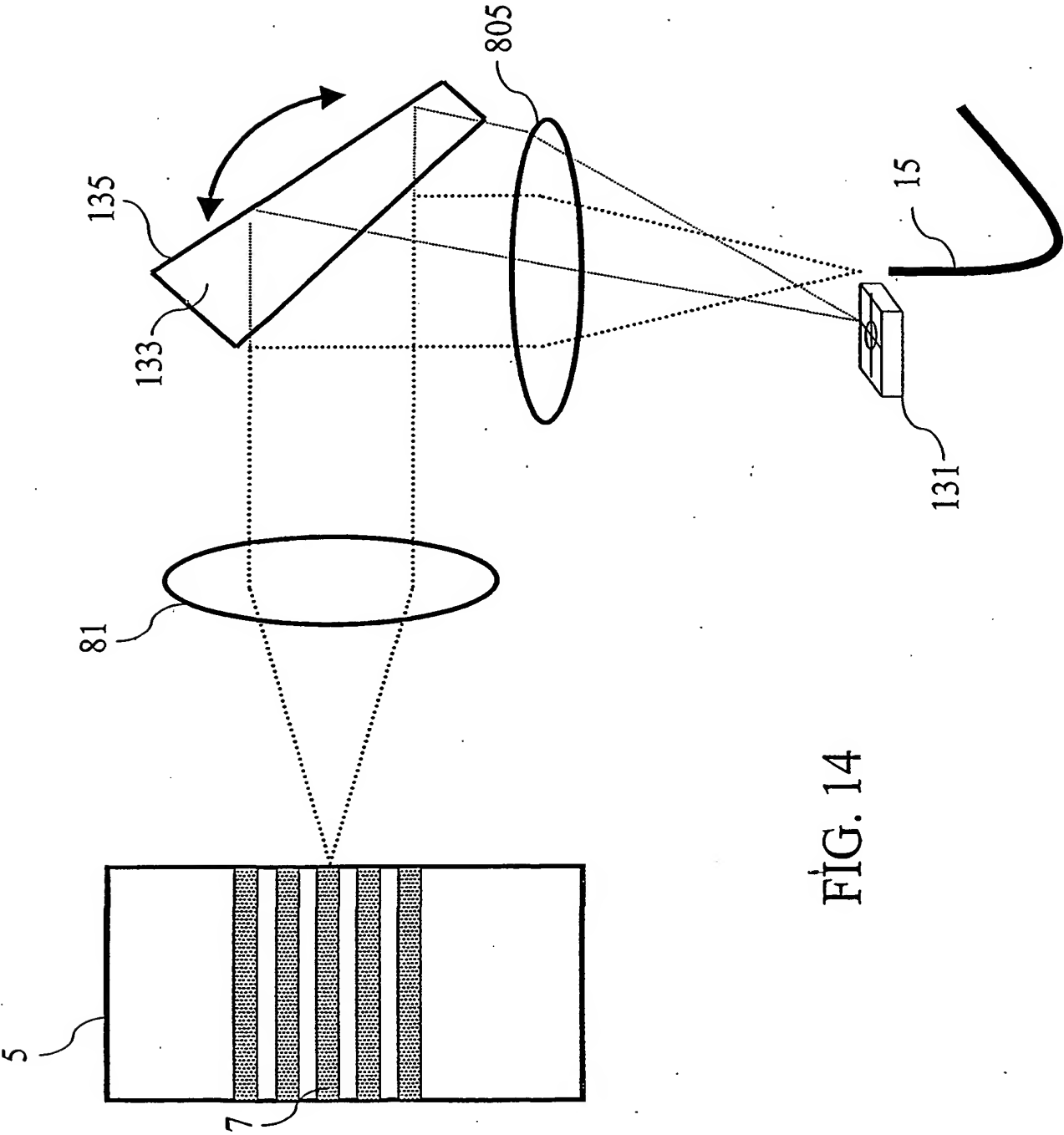


FIG. 14

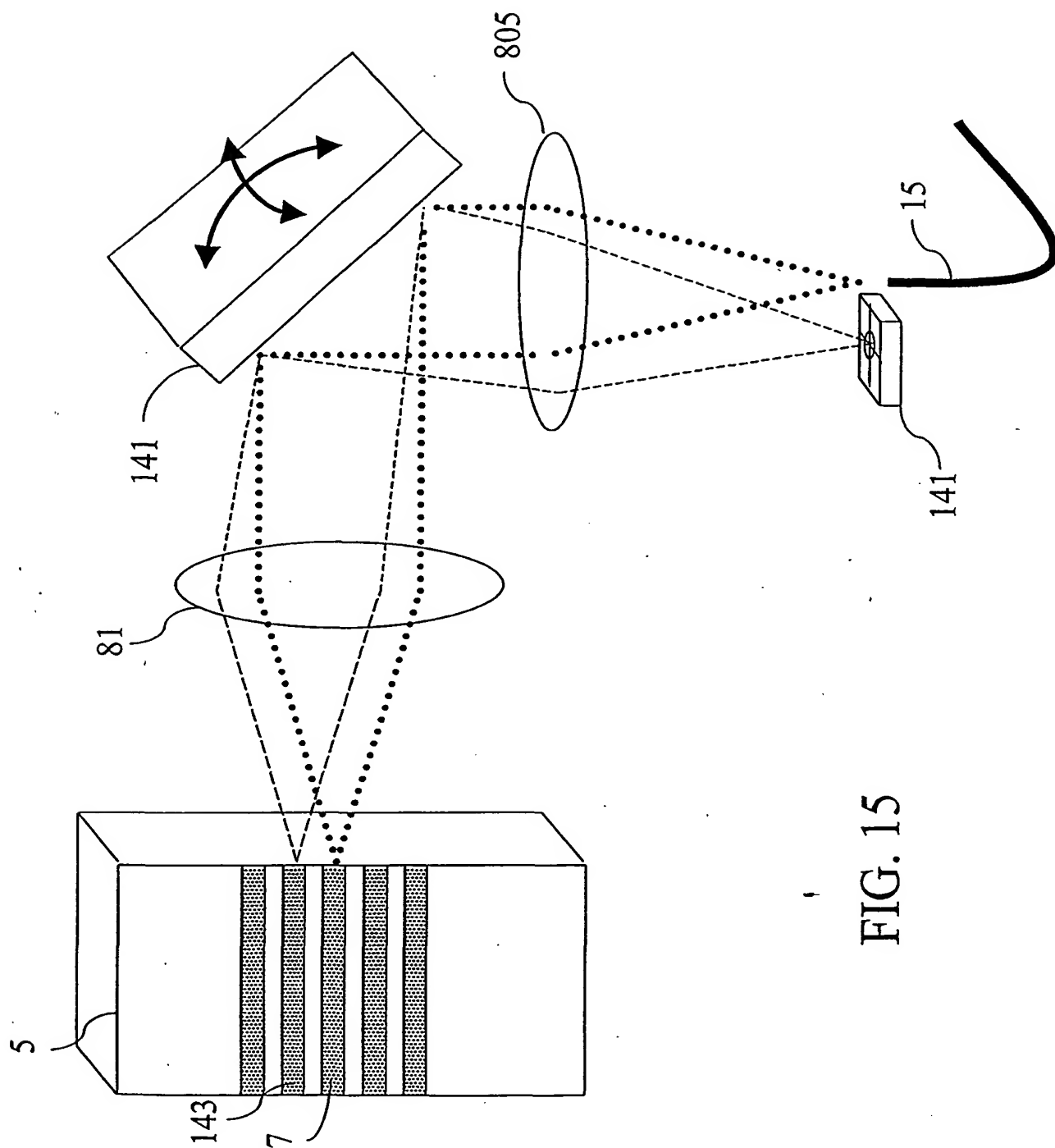


FIG. 15

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/45343

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G01J 4/00

US CL : 250/227.19

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 250/227.19, 227.21, 227.18, 227.27, 227.11; 385/8, 13, 31, 39; 359/244, 245

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, E	US 6,316,764 Ba (HEFFNER et al) 13 November 2001 (13/11/01) see entire document.	1-94

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

13 MARCH 2002

Date of mailing of the international search report

11 APR 2002

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